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A FEW COMMENTS ON $\nu_e \leftrightarrow \nu_\tau$ OSCILLATION PARAMETERS

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Abstract. Some remarks on Conforto's mass and mixing parameters in the light of results of other experiments are presented. Accelerator and reactor neutrino experiments, the SN 1987A neutrino burst, beta decay spectrum measurements and solar neutrino problem are considered.

Key words: beta-ray spectra, neutrino, neutrino mass and mixing, neutrino oscillations, accelerator neutrino, reactor neutrino, supernova neutrino burst, solar neutrino.

1. INTRODUCITON

The search for non-zero neutrino mass and mixing has been the aim of various neutrino experiments for years. There are also experiments — although their number is rather limited — where non-zero mass and mixing effects were thought to have been seen, but, as a rule, thorough further investigations have nullified the non-zero results. The purpose of this paper is to present some remarks on Conforto's [1] non-zero mass and mixing parameters in the light of the results of other experiments.

2. CONFORTO'S OSCILLATION PARAMETERS

The data from the BEBC, CDHS and CHARM beam dump experiments were jointly examined by Conforto [1]. The joint information on asymmetry

$$A = (\nu_\mu \text{ flux} - \nu_e \text{ flux}) / (\nu_\mu \text{ flux} + \nu_e \text{ flux})$$

shows the existence of $\nu_e \leftrightarrow \nu_x$ oscillations (with $x \neq \mu$ and possibly $x = \tau$) with the difference of the neutrino mass squared Δm^2 and mixing angle θ [1]

$$\Delta m^2 = (377 \pm 27 \pm 7)\ \text{eV}^2, \tag{1}$$

$$\sin^2 2\theta = 0.48 \pm 0.10 \pm 0.05. \tag{2}$$

Since at LEP the ALEPH, DELPHI, L3 and OPAL precision determinations of the Z^0 width allow for only three light neutrino species the supposable oscillations, if anything at all, are just $\nu_e \leftrightarrow \nu_\tau$ oscillations. Motivated by charged lepton and quark masses, it is natural that while compared with the tauneutrino mass the electron neutrino mass is negligible. So, oscillation parameters (1) and (2) seriously hint at the existence of a neutrino with a mass of about 20 eV and with a relatively large mixing in the electron neutrino weak interaction eigenstate.

For the large Δm^2 of interest here the tight limits exist on oscillations, involving ν_μ [2], and it would be sufficient to consider here only two neutrino species — ν_e and ν_τ. The neutrino weak eigenstates are linear combinations of the mass eigenstates with mass m_1 and m_3:

$$\begin{aligned} |\nu_e\rangle &= \cos\theta|\nu_1\rangle+\sin\theta|\nu_3\rangle, \\ |\nu_\tau\rangle &= -\sin\theta|\nu_1\rangle+\cos\theta|\nu_3\rangle. \end{aligned} \tag{3}$$

3. ACCELERATOR EXPERIMENTS

In addition to CERN beam dump experiments Conforto has analyzed, limits for $\nu_e \leftrightarrow \nu_\tau$ oscillations are given by the Fermilab E531 Collaboration [2]. They used a hybrid emulsion spectrometer installed in Fermilab wide-band neutrino beam looking for τ-lepton decays to find ν_τ interactions. No such candidates were found. This is very restrictive to $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in large Δm^2 range but, as ν_e component in the wide-band beam is small, it leaves more room for $\nu_e \leftrightarrow \nu_\tau$ oscillations: near $\Delta m^2=400$ eV^2, for instance, $\sin^2 2\theta<0.17$. At the same time note that in the E531 experiment the maximum of the L/E distribution for the electron neutrino beam happened to be in the region where the probability for $\nu_e \leftrightarrow \nu_\tau$ transition for 20 eV ν_τ is just minimal. In addition, there are systematic errors in the normalization of the E531 data as a result of which the upper bound on $\sin^2 2\theta$ might weaken by at least two times (A. I. Mukhin, pers. comm.), and is safe for Conforto's mixing parameters.

4. REACTOR EXPERIMENTS

A nuclear power reactor is an intense source of electron antineutrinos with a relatively low energy (1—15 MeV). So, for a large Δm^2 ($\Delta m^2>10$ eV^2) the oscillation length is much shorter than the distance L between the reactor and any detector position, and one can only measure the average effect of neutrino oscillations viz. the reduction of neutrino flux by $(1-0.5\sin^2 2\theta)$ times.

Though the search for neutrino oscillations was provided at many reactors for a large Δm^2, the most trustworthy upper limit of $\nu_e \leftrightarrow \nu_\tau$ mixing parameter has been obtained by Caltech-SIN-TUM Collaboration [3] at Gösgen (Switzerland) 2800 MW reactor: $\sin^2 2\theta<0.21$ (90% CL) for $\Delta m^2>5$ eV^2 by assuming a neutron half-life 622 sec. By using the last PDG [4] average $t_{1/2}=(616\pm1.5)$ sec, we get the slightly weaker upper limit $\sin^2 2\theta<0.23$. After a thorough investigation within several years, the Caltech-SIN-TUM Collaboration concludes that it seems difficult to improve the upper bound on $\sin^2 2\theta$ for large Δm^2 for the reason of inevitable systematic errors due to uncertainties in:
— the detector efficiency,
— the reactor antineutrino spectrum,
— the reactor power.
Considernig the above-said there is a reason to think that although there exists a slightly stronger upper limit on $\sin^2 2\theta$ [5], the systematic errors are underestimated there. In any case the discrepancy between the Gösgen result and Conforto's mixing is only in 2σ level, and is not so very drastic.

5. 17 keV NEUTRINO

As there are only three light neutrino species, the 17 keV neutrino would certainly exclude the existence of a 20 eV neutrino.

In 1985 Simpson [6] reported observing a kink in the tritium β decay spectrum, indicating that some of the neutrinos in tritium decay have a mass of about 17 keV. Several experiments are performed to check it, using β decay of different nuclei and electron capture with inner bremstrahlung (IBEC). A review of the current situation is given, for instance, in ref. [7]. Up to now we have results that support and others which do not support the existence of the 17 keV neutrino. Simpson used a semiconductor detector. Semiconductor detectors were also used in other experiments, where positive results were attained. Zagreb IBEC experiment gave positive result as well. However, it is essential that all β-spectrum experiments with magnetic spectrometers had given only negative results. The latest one — the high sensitivity search for a 17 keV neutrino at the Institute for Nuclear Study of the University of Tokyo [8] — gave negative indication with an upper limit of 0.095% on the mixing strength. So the 17 keV neutrino is not a sign against the existence of a 20 eV tauneutrino.

6. ENERGY AND TIMING OF SN 1987A NEUTRINO EVENTS

Conforto's oscillation parameters are obviously in the domain of interest concerning the SN 1987A neutrino burst. We have explored the problem [9] and found that, considering the Conforto parameters, some specific features of the Kamiokande II and the IMB SN 1987A neutrino events are well explained.

7. TRITIUM BETA DECAY SPECTRUM MEASUREMENTS

The possibility of measuring the neutrino mass and the mixing in the experimental studies of the beta decay electron spectra has been discussed in ref. [10]. For two neutrino mixing (3) the probability of β-decay for ground state transition is

$$\begin{aligned} W_\beta(E_0) &= \cos^2\theta\, W_1(E_e), \quad E_0 - m_3 < E_e < E_0 - m_1, \\ W_\beta(E_0) &= \cos^2\theta\, W_1(E_e) + \sin^2\theta\, W_3(E_e), \quad E_0 - m_3 > E_e, \end{aligned} \tag{4}$$

where E_0 is the sum of electron kinetic energy E_e and neutrino energy, m_i is the neutrino mass, and

$$W_i(E_e) \sim p_e E_e (E_0 - E_e) \left[(E_0 - E_e)^2 - m_i^2 \right]^{1/2} . \tag{5}$$

Mixing (2) is almost sufficient to expect a noticeable effect in tritium beta decay experiments. So it is possible that the lower limit on electron antineutrino mass, reported for years by the ITEP group [11, 12] (though not confirmed by others), give a sign of ν_e mixing with ν_τ having a corresponding mass. Namely, it is remarkable that the lower bound on electron antineutrino mass 17 eV of the ITEP group is near the m_3 mass limits

$$18.7\ \text{eV} < m_3 < 24.0\ \text{eV} \tag{6}$$

one gets from (1) using $m_1 = 0$ or experimental upper bound on electron neutrino mass 13 eV from ref. [13], which is the upper limit on m_1 as well. Perhaps it explains the disagreement between the lower bound 17 eV of the ITEP [12, 13] group and the upper bounds 13 eV of the INS [13] group and 9.3 eV of the Los Alamos [14] group. Maybe the discrepancy is caused by an interplay of the background and energy resolution. Suppose that the ITEP group had the resolution sufficient to see the disappearance of the ν_3 component from the tritium β-spectrum but, due to the background, the mass m_3 was interpreted as the reported lower limit on electron antineutrino mass.

In any case, to visualize the tiny effects of non-zero neutrino mass is possible only through a thorough statistical analysis. The proposal for tritium β-decay research groups is: to make the statistical analysis of tritium β-spectrum using formulae (4) and (5) taking into account corrections to theoretical tritium β-spectrum due to the difference of the neutrino mass squared (1) and mixing (2) (as it was done searching in 17 keV neutrino).

8. GALLEX AND SAGE RESULTS

The GALLEX Collaboration [15] observed the solar neutrino signal 83 ± 19 (stat.) ± 8 (syst.) SNU and the SAGE Collaboration observed (A. I. Mukhin, pers. comm.) 58^{+17}_{-24} (stat.) ± 14 (syst.) SNU. The calculated standard model capture rate for the ^{71}Ga experiment is 132^{+20}_{-17} SNU [16]. Oscillations $\nu_e \leftrightarrow \nu_\tau$ reduce the detected solar neutrino flux as $0.5 \sin^2 2\theta \cdot 100\%$ of the electron neutrinos pass over the tauneutrinos, which are undetectable in charged-current detectors. The Conforto's $\nu_e \leftrightarrow \nu_\tau$ mixing parameter reduces the calculated capture rate 132 SNU by 27—40 SNU. For solar neutrino deficit from the chlorine detector measurements there are other potential solutions: the MSW matter mixing effect and some extensions of the standard solar model.

9. SUMMARY

What concerns Conforto's oscillation parameters, it is seldom left unmentioned that these are a result of a questionable combined analysis and moreover excluded by certain accelerator and reactor oscillation experiments. In reviews of the present experimental knowledge of the properties of the τ and ν_τ this interesting possibility usually remains unmentioned (see for example [17]). It seems that such an attitude is hardly justified. As a matter of fact, the E531 upper bounds on $\nu_e \leftrightarrow \nu_\tau$ oscillation parameters themselves need to be corrected, and the expected upper bound on $\sin^2 2\theta$ is safe for Conforto's parameters. Most serious facts opposed to are the results of the reactor oscillation experiments, and even these are well within two standard deviations. In any case it would not be reasonable to exclude lower limit (2) without further investigation.

As to the "supporting" signs in SN 1987A neutrino burst, in β-spectrum and solar neutrino capture rate is another matter, but the neutrino physics is a field where it is reasonable to explore attentively any non-zero sign.

It is promising that the study of electronneutrino oscillations into any other type of neutrino is just going on at IHEP-JINR Neutrino Detector (S. A. Bunyatov, pers. comm.) by measuring the dependence of the number of the charged current ν_e interactions on the variable L/E and there is a good opportunity to search the neutrino oscillations in the interesting region, which could allow a detection of a cosmologically significant ν_τ mass.

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MÕNED MÄRKUSED $\nu_e \leftrightarrow \nu_\tau$ OSTSILLATSIOONI PARAMEETRITE KOHTA

Laur PALGI

On vaadeldud Conforto poolt CERN *beam dump*-eksperimentide analüüsist saadud neutriino massi ja segunemise parameetrite kooskõla teiste kiirendi ja reaktori neutriinoeksperimentide ning SN 1987A neutriinosähvatuse, päikeseneutriino voo ja beetaspektri mõõtmise tulemustega.

НЕКОТОРЫЕ ЗАМЕЧАНИЯ ПО ПАРАМЕТРАМ $\nu_e \leftrightarrow \nu_\tau$ ОСЦИЛЛЯЦИИ

Лаур ПАЛЬГИ

Рассмотрено согласие между параметрами массы и смешивания нейтрино, полученными Конфортом из анализа результатов экспериментов типа beam dump в ЦЕРНе, и результатами измерения других нейтринных экспериментов на ускорителях и реакторах, а также нейтринной вспышки SN 1987A, потока солнечных нейтрино и спектров бетараспада.