NEUTRINO REST MASS AND ANOMALY IN THE TRITIUM BETA SPECTRUM.

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ABSTRACT

Results of the "Troitsk ν-mass" experiment on the search for the neutrino rest mass in the tritium beta-decay are presented. Study of time dependence of anomalious, bump-like structure at the end of beta spectrum reported earlier gives indication of periodic shift of the position of the bump with respect to end-point energy with period of 0.5 year. New upper limit for electron antineutrino rest mass $m_\nu < 2.5 eV/c^2$ is derived after accounting for the bump.

1 INTRODUCTION

The direct or kinematical approach to the search for the neutrino rest mass is based on the study of neutrino momentum-energy balance in weak semileptonic decays. In this case any dependence on the leptonic or flavor quantum numbers is excluded. Maximal sensitivity to mass effect may be attained when neutrino energy is minimal. Such situation usually can be obtained in three-body or multibody decay. Total energy spectrum of visible particles in the vicinity of maximal energy is dominated by the neutrino phase space volume which is proportional to pE where p is momentum and E total energy of the neutrino. Deviation of this product from p^2 allows one to deduce the mass of neutrino. Smallness of this product defines fast decreasing of the measured spectrum intensity by approaching end point energy and makes main difficulty of the experiment. At present lowest limit for electron neutrino mass was achieved by the study of the shape of tritium beta spectrum near its end point. The decay of tritium provides a unique opportunity for such experiments due to low end-point energy, high specific activity, the lowest Z, and possibility to calculate most of the corrections for its super allowed spectrum. Putting in operation of new spectrometric facilities in Troitsk (Moscow) 1) and in Mainz 2) allowed to observe details of beta-spectrum at about $5 - 15\,eV$ below the end point. Besides significant improvement of upper limit for the neutrino mass the experiment in Troitsk revealed existence of anomalious structure of bump-like shape (for differential spectrum mode) in the region of $5 - 15\,eV$ below end point with integral intensity about

10^{-10} of total decay rate. Very enigmatic feature of this structure appeared to be shift of its position with time.This structure in the condition of absence of understanding of its nature plays role of systematics for the search of neutrino mass, strongly increasing possible error.

2 INTEGRAL ELECTROSTATIC SPECTROMETER WITH ADIABATIC MAGNETIC COLLIMATION

The development of a new approach to spectroscopy of tritium started at the end of 1982 at the Institute for Nuclear Research of the Russian Academy of Sciences (Troitsk). The main ideas were published in [3, 4, 5]. Independently similar ideas emerged at the Institute for Physics of Mainz University [6]. The main feature of this approach is an integral electrostatic spectrometer with strong inhomogeneous magnetic field providing guiding and collimation of the electrons.The earlier variant of such type spectrometer was proposed for spectroscopy of electrons with energy below hundred eV . Extension of working area of the spectrometer toward a few tenth KeV proved to be possible due to special shaping of magnetic and electric fields. Main advantage of such spectrometer is large improvement in energy resolution, amounting to $3,5-4\,eV$ (FW) and luminosity.

The strong guiding magnetic field in the spectrometer permitted to couple it in a natural way with the gaseous windowless tritium source also with strong magnetic field. This approach was developed in Troitsk set-up. An essential part of the spectrometer and of the tritium source is a set of superconducting solenoids which produce a continuous longitudinal magnetic field through the whole setup. The cylindrical electrode in the central part of the spectrometer is an integral electrostatic analyzer. The details of the set-up design and of the measurement procedure may be found in [1], [7], [8] and [9].

The tritium spectrum was measured by changing the spectrometer high voltage in steps. Direction of high voltage scanning was reversed each cycle ($1-2$ hours). Altogether, in the period of 1994-1998 years the time of measurement amounted to about 200 days. The measurements were made in the range of the spectrometer potential from 18000 to 18770 V. Analysis of data were done by fit of theoretical spectum with all the correction and some variable parameters to experimental spectrum by means of χ^2 procedure.

As a basic set of variable parameters in χ^2 fit procedure we used 4 parameters : normalization factor, end point energy, background and m_ν^2. The final state spectrum of decay product (FSS) was taken from most resent theoretical calculations [10].

Corrections for inelastic interactions of electrons in tritium gas as well as the FSS spectrum strongly correlate with mass of neutrino and some other parameters of the spectrum. Special system with electron gun and magnetic transportation of the electrons to the rear part of the source allowed to measure integral spectrum of inelastic losses of electrons in tritium as well as density of the source.

3 ANOMALIOUS STRUCTURES IN THE SPECTRUM

Fitting of the data with 4 basic variable parameters after introducing of all the corrections resulted in the value for m_ν^2 equal to $-10-20, eV^2$ mostly independent of lower

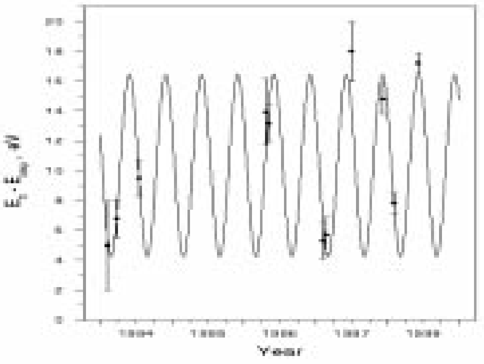

Figure 1: The step position dependence on the calendar time of measurements. Parameters of the fitted sinusoid are: Period 0,5036 ± 0,0023 year, mean value 10,3 ± 0,4 *eV*, amplitude 6,1 ± 0,55 *eV*, phase 2,8 ± 0,16 *rad*.

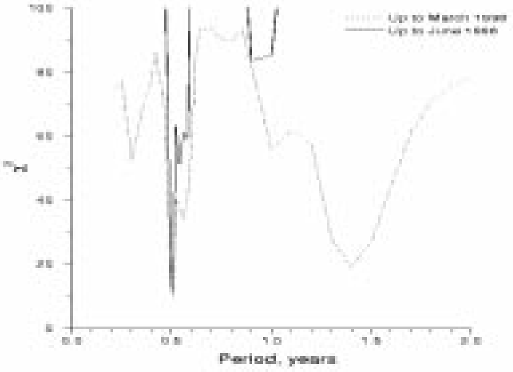

Figure 2: The χ^2 dependence on the period of sinusoid fitted to step position plot versus calendar time of measurement. Period value was scanned and 3 other parameters were left variable. Solid line corresponds to all the run fit and dotted line with the last run (June 1998) being omitted

boundary (E_{low}) of part of the spectrum taken for analysis. The negative values for m_ν^2 obviously indicated that there exist some systematic effects not taken into account in the calculation of the theoretical spectrum $^{1)}$. Inspection of the spectra showed that there is small enhancement near to the end point shaped like small step imposed on the regular spectrum. In differential spectrum such addendum would be seen as a bump-like structure with small width (about resolution of the spectrometer). Addition to the theoretical spectrum of step-like function with variable height (size) and position (E_{step}) brought m_ν^2 to about zero thus totally eliminating the negative value problem.

The fit with these additional variables resulted in values for ΔN_{step} in average $6 \cdot 10^{-11}$ of total decay intensity and $E_0 - E_{step}$ varying within $5 - 16\,eV$ In all the runs fit with step function made m_ν^2 value about zero within fit errors. Positions of the step with respect to end point energy for all the runs and subruns proved to be changeable. Plotting the values of $E_0 - E_{step}$ versus calendar time of corresponding run revealed very suprizing feature of the bump structure consisting in periodical change of its position. This periodicity is shown in Fig. 1 and demonstrate that a sinusoidal curve may be fitted to all the points.

The period of oscillation of step position proved to be equal to $0,504 \pm 0,003$ years, mean value of the position $10,3\,eV$ and amplitude $6,1\,eV$. Size of the steps also undergo variation so that the maximal size correspond to maximal shift. Unfortunately the relative error of this parameter is significally larger than the position value error. Dependence of χ^2 on the value of the period is shown in Fig. 2. It demonstrates that half a year period gives satisfactory description of the data.

Combining data of all the 4 years in one year plot confirm that the variations have biseasonal character (see Fig. 3). Of course present set of data needs to be sufficiently extended. In particular shortage of measurement within the period July - December and absence of continuous measurement during all the year make possible to fit more complicated periodic curve. At the moment seems to be impossible to propose any "customary"explanation of this phenomenon. The proximity of the period to an astronomical

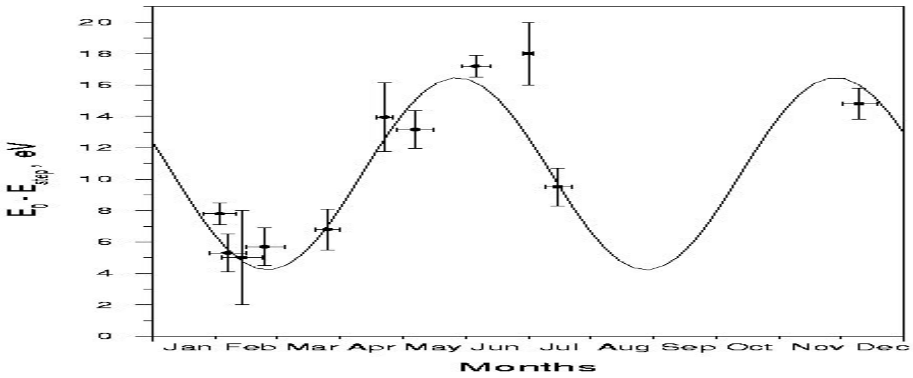

Figure 3: The plot of step positions versus time of the year. Fitted sinusoid is the same as in Fig. 2, but with the period being 0.500 year. Horizontal bars are lengh of the run.

period and other features of this phenomenon make excusable considering of exotic explanation of it. One of such explanations stems from long-standing discussion of the effect produced by capture of relic very low energy neutrino by tritium atoms with emission of monochromatic electrons 11). For free neutrino the energy of such electron must exceed or be the same as end-point energy. In order to produce the bump intensity, corresponding to 10^{-10} of total decay rate it is necessary to suppose existence of neutrino cloud with density as high as $0,5 \cdot 10^{15} \nu/cm^3$, that is 10^{13} times more than generally accepted average density of relic massless neutrino. Such density corresponds to degenerated neutrino spectrum with Fermi-energy of about $5,5\,eV$.

Observation of bump below end point of beta spectrum corresponds to capture of neutrino with negative energy, and to assumption of binding of neutrino in the cloud. The binding energy from the above data may be estimated as $15 - 20\,eV$ and could vary over the cloud. Binding of neutrino seems to be necessary for stability of such cloud provided for example by the neutrino long range (about the size of cloud) self interaction. In order to explain the half year modulation period one may suppose that the neutrino cloud has shape of flattered spheroid with axis of symmetry inclined with respect to normal direction to Eucliptic plane. In case of binding energy gradually decreasing to the periphery of the cloud, the Earth in its movement produces the half a year periodical modulation.

The size of neutrino cloud, if exists, is of the order $10^{14}\,cm$ and it does not contradict to average density of relic neutrino in the Universe. The possibility of existence of such cloud with massive neutrino from the point of view of contradiction to astrophysical and elementary particle data was ones considered in 12) with conclusion that existing data do not contradict to such picture if to abstract oneself from the problem of trapping of relativistic neutrino in potential well. Of course this scenario is extremely speculative and may be accepted only as a heuristic idea until totally convincing experimental confirmation as well as certain theoretical background will be presented.

Experimental data up to now does not exclude, that shape of the end-point region is more complicated than one-bump structure. Nevertheless it appears to be well established that centrum of gravity of the enhancement is below end-point of the tritium beta-spectrum, and it undergoes periodical shift with respect to end-point.

4 NEUTRINO MASS UPPER LIMIT

Deduction of the neutrino mass from the data in presence of unexplained anomaly requires a special approach. As it was mentioned earlier the procedure accepted for this purpose consisted in addition to theoretical spectrum of the step function with two variable parameters supposing that such addition may describe in the first approximation local enhancement in the beta-spectrum near to end-point. Distortion of beta-spectrum imitating the m_ν^2 effect should also be concentrated near end point, otherwise the effect relatively rapidly sinks in growing statistical errors at increasing $E_o - E$, but unlike the local enhancement it appears as an addition to (for negative m_ν^2) or deficiency (positive m_ν^2) of the spectrum intensity that is linearly increasing with $E_0 - E$.This difference allows to separate both effects in fit procedure. Of course the size and position of the step being introduced as a free parameter, correlate with m_ν^2 and it increases the final error of neutrino mass thus acting as a kind of systematic error. This increase sufficiently compensates the uncertainty of substitution of an a priory unknown anomaly shape by the step-like function. Other systematical errors come mostly from the uncertainties of parameters of the correction factors which are introduced in the spectrum before the fit. These factors are: trapping effect, source density, possible variation of excitation and ionization parts of the inelastic cross section, dead time, and influence of high exited FSS part. A remarkable property of total systematic error is its decreasing with increasing of E_{low}, Taking into account that fit error of m_ν^2 increases with increasing of E_{low} one may select the optimal E_{low}, when the total error, including both the fit and systematic error taken in quadrature, is minimal. The results for m_ν^2 for all the runs are given below:

$$1994 \;\; m_\nu^2 = -2,7 \pm 10,1_{fit} \pm 4,9_{syst}\, eV^2/c^4 \tag{1}$$

$$1996 \;\; m_\nu^2 = +0,5 \pm 7,1_{fit} \pm 2,5_{syst}\, eV^2/c^4 \tag{2}$$

$$1997(1) \;\; m_\nu^2 = -8,6 \pm 7,6_{fit} \pm 2,5_{syst}\, eV^2/c^4 \tag{3}$$

$$1997(2) \;\; m_\nu^2 = -3,2 \pm 4,8_{fit} \pm 1,5_{syst}\, eV^2/c^4 \tag{4}$$

$$1998 \;\; m_\nu^2 = -0,6 \pm 8,1_{fit} \pm 2.0_{syst}\, eV^2/c^4 \tag{5}$$

The combined value in quadrature:

$$m_\nu^2 = -2.0 \pm 3,4_{fit} \pm 2,3_{syst}\, eV^2/c^4 \tag{6}$$

Combined systematic error is obtained by averaging with weights of fit errors. From here one may obtain the 95% C.L. Bayesian upper limit for m_ν:

$$m_\nu < 2,5\, eV/c^2; \tag{7}$$

5 ACKNOWLEDGMENTS

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