DIRECT SEARCH FOR MASS OF NEUTRINO

V. M. LOBASHEV
Institute for Nuclear Research; Academy of Sciences of Russia;
60-th October Anniversary Prospect 7a; 117312 Moscow, Russia
E-mail: lobashev@al20.inr.troitsk.ru

and

ABSTRACT

Status of experiments on the direct search for the neutrino rest mass is reviewed. 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 anomalous, bump-like structure at the end of beta spectrum ,reported earlier, gives indication of periodic shift of its position with respect to end-point 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 problem of neutrino rest mass remains to be one of the most actual in Elementary Particle Physics and Cosmology. 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.Reduction 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. 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 reduction of the neutrino mass upper limit the experiment in Troitsk revealed presence in the spectrum of anomalous 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 turned out to be periodic 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 the neutrino mass, strongly increasing possible error.

2. Status of the ν_μ, ν_τ rest mass search.

The experimental situation in the search for the rest mass of ν_μ, ν_τ reached now more or less quiet state and there is no reason to expect dramatic changes in the forseeable future. As to ν_τ the lowest limit on its mass was obtained by the collaboration ALEPH. Present limit $m_{\nu_\tau} < 18.2\ MeV/c^2$ at 95% C.L.[15] was obtained by twodimensional fit on energy and invariant mass of secondary particles in two decay branches: $\tau - 3\pi^\pm\nu_\tau$ and $\tau - 5\pi^\pm(\pi^0)\nu_\tau$. The interest to MeV size limit for ν_τ stems from some cosmological models with unstable heavy neutrino.Recent limit still leaves a small room for such models. The experimental situation in the direct search for the mass of ν_μ is practically settled. The most accurate experiment was done at PSI[16] . It consists by measuring momentum of muon in $\pi - \mu\nu_\mu$ decay with stopped pion in surface source mode.The spectrum of muons produced by pions stopped in proton target has a sharp step. The muons at the step were born by pions decaying at rest on the very surface of proton target. Measurement of muon momentum in semicircular spectrometer provided precise value of muon momentum for pion decay at rest(3.7 ppm). Other input value for deriving m_ν are pion and muon masses.The muon mass is one of the most accurate measured value (precision of about 0.3 ppm) and major problems come from pion mass precision.

Most accurate measurement of pion mass was done by precise measurement of the energy of 4d-3f transition in pionic atom of magnesium with crystal-diffractional spectrometer with accuracy of about 2.7 ppm [17]. Use of this value for calculation m_ν^2 gave odd result consisting in negative value at the level of 6 standard deviation. The problem was soon recognized as a result of uncertainty in screening factor in mesic atom.Accounting for this factor produced two solutions for pion mass , one of which gave above mentioned odd value and other provided m_ν^2 about zero. Recently new measurements of 5g-4f transition in mesic nitrogen [18] allowed to derive pion mass with smaller accuracy but free from previous uncertainties.The new value definitely favours to larger pion mass solution that is to m_ν^2 about zero. The upper limit for mass of muonic neutrino from these experiments is $m_\nu < 0.17\ MeV/c^2$ C.L. 0,9. Next serie of experiments is directed for improvement of pion mass accuracy below 1 ppm. This is difficult task and it will take some years of development. Unfortunately at the moment there are no competitive proposals for measurement of muonic neutrino rest mass on significally lower level.

3. Search for electron antineutrino rest mass

The shape of the beta-spectrum with nonzero neutrino mass is

$$W(E,Z) = A \cdot F(E,Z) \cdot E \cdot p \cdot \Sigma W_i (E_{oi} - E)\sqrt{(E_{oi} - E)^2 - m_\nu^2 c^4} \qquad (1)$$

where E is the total energy and p is the momentum of electron; W_i is the probability, and E_{oi} is the end-point energy of the partial decay into i-th final state. The effect of nonzero neutrino mass emerges as a cut-off of the spectrum at $E_{oi} - E = m_\nu^2 c^4$, and intensity deficiency smoothly declining to lower energy. 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.

History of the search for neutrino mass in the tritium beta decay counts almost 50 years. An illustration of the experimental progress during this time is given in Fig. 1. In 1980 steady improvement of upper limit for neutrino mass was suddenly speeded up by report of the ITEP group from Moscow on the observation of the neutrino mass effect corresponding to the rest mass of about 30 eV/c^2 [19]. This report stimulated more than 20 experimental proposals with an intention to check this claim. After several years the experimental groups from Zurich [20], Tokyo University [21], Los Alamos [22], and later Livermor [23] produced results which refuted ITEP group claim, but revealing, also, many difficulties in measuring and analysing the beta-spectra.

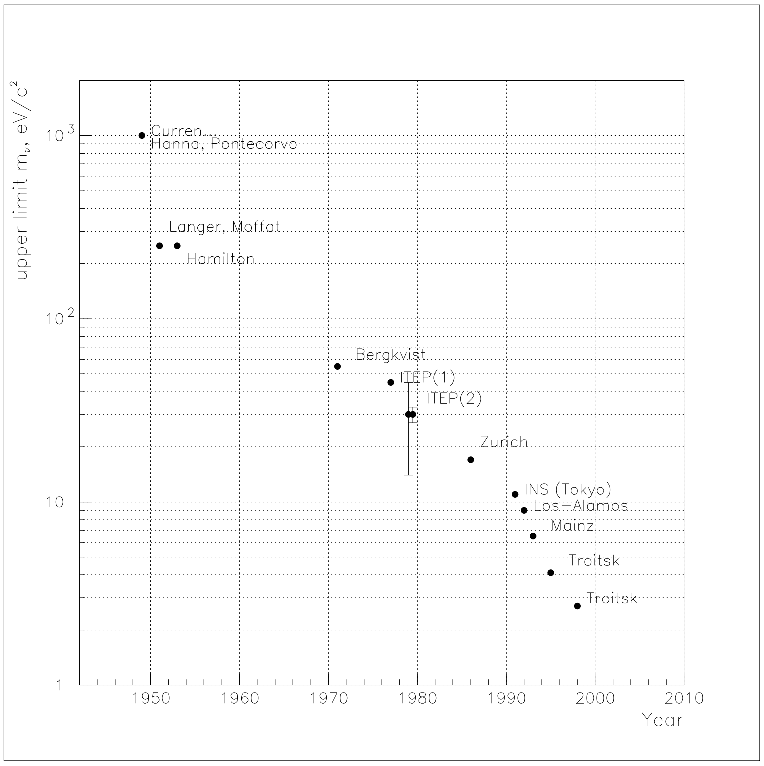

Fig. 1. The history of progress of upper limit improvement in neutrino mass measurement in tritium beta-decay.

Much efforts were made to develop a new tritium source. The most radical step here was done by Los-Alamos group by construction of windowless gaseous tritium source with strong solenoidal magnetic field transporting electrons to a spectrometer of the Tretyakov type[24]. The history of progress in neutrino mass measurement in the tritium beta-decay is shown in Fig. 1.

4. The Troitsk ν-mass set-up.

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) [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 early variant of such type spectrometer was proposed for spectroscopy of electrons with energy below hundred eV [13],[14]. Extension of application area of the spectrometer toward a few tenth KeV proved to be possible due to special tailoring of magnetic and electric fields. The Troitsk setup is shown in Fig. 2. 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 all set-up. 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 comprising the second essential part of the Troitsk set-up. Gaseous tritium source has a number of advantages in comparison with solid state source. The most essential are: no correction for backward scattering, weakness of interactions of tritium with other molecules, easy control for admixture, absence of charging effects. Details of the set-up design and of the measurement procedure may be found in [1],[7], [8] and [9].

The gaseous tritium is injected at the center of a 3 -meter-long tube inside the solenoids and is being pumped out by mercury diffusion pumps installed at both ends of the tube. After additional compression in the buster mercury pump and after purification tritium returns to the injection point, thus providing continuous circulation. 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). The measurements were made in the range of the spectrometer potential from 18000 to 18770 V. Data aquisition system allowed to record amplitude and time of each detector pulse. High voltage stability was checked by independent measurement by 3 attenuators. Altogether, in the period of 1994-1998 years the time of measurement amounted to about 200 days. Analysis of data was done by fit of theoretical spectum with all the correction factors and some variable parameters to experimental spectrum by means of the minimum χ^2 procedure.

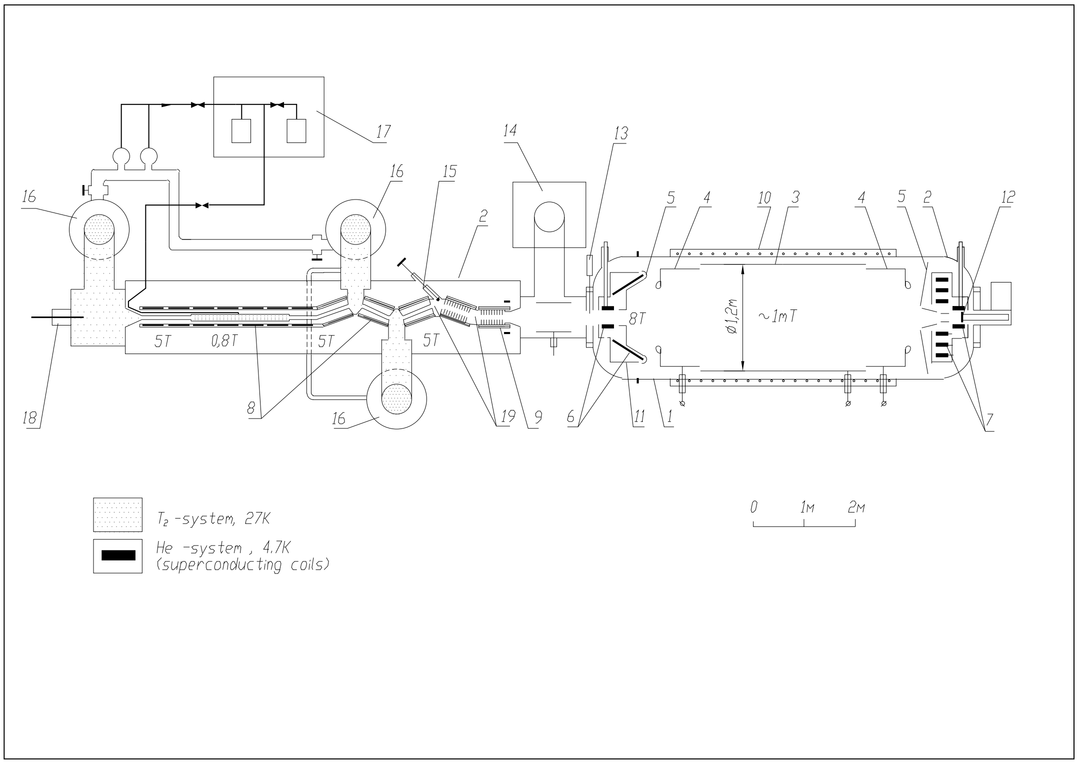

Fig. 2. Experimental set-up. (1),(2) vacuum tank; (3),(4) electrostatic analyzer; (5) grounded electrode; (6),(7),(8),(9) superconducting coils; (10) warm coil; (11)LN_2 jacket; (12) Si(Li) detector; (13) fast shutter;(14) Ti-pump ; (15) cold valve; (16) Hg diffusion pump; (17)T_2 purification system; (18) electron gun;(19) argon pump.

Experimental spectrum was corrected for dead time and pile-up, drift of the source intensity, for the cutting out of the part of the detector spectrum, and for events of tritium decay into spectrometer. The latter display themselves as bunches of pulses with instant counting rate corresponding to probability less then $10^{-4} - 10^{-5}$ in comparison with regular rate. The search for such events was possible in the area of low counting rate from 18530 to 18770 eV. Below 18530 the average of bunch counts is subtacted, with increase the statistic error.

Theoretical spectrum was taken in classical form. Extension of it to negative (unphysical) values of m_ν^2 was taken as in [1] . The spectrum was convoluted with integral spectrum of energy losses of the electrons in the source, the final states spectrum and corrected for trapping effect in the source. The latter was the reason of an intensity rise of the spectrum toward low energy reported in [1]. The final state spectrum of decay product (FSS) was taken from most recent 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 adiabatic 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. These measurements gave total inelastic interaction cross-section of electron with molecules of tritium in good accordance with theoretical value $3.45 \cdot 10^{-18} cm^2$ at electron energy $18.6\ keV$. Spectrum of inelastic losses was found to be different from usually accepted. In particular ratio of excitation to ionisation parts of it proved to be equal to 0.51/0.49, in disagreement with usually quoted 0.4/0.6. 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 fit was made for spectrum interval with low energy boundary (E_{low}) from 18000 eV to 18530 eV and upper boundary 18770 eV.Variation of E_{low} is very important for recognizing systematical effects.

5. Anomalous structure in the spectrum

Fitting of the data with 4 basic variable parameters after introducing of all the corrections resulted in the value of m_ν^2 equal to $-10 - 20\ eV^2$ mostly independent of (E_{low}). The negative values for m_ν^2 obviously indicated that there exist some systematic effect not taken into account [1)]. Inspection of the spectra showed that there is small enhancement near the end point which resembles small step superimposed on the regular spectrum. In differential mode 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 hight (size) and position (E_{step}) made the theoretical and the experimental spectra consistent over all the measured part of it and brought the value of m_ν^2 to about zero thus eliminating the negative value problem (see Fig.3 and Fig. 4).

Parameters of the step function turn out to vary from run to run but resulted in average for ΔN_{step} about $6 \cdot 10^{-11}$ of total decay intensity (besides the last run) and $E_0 - E_{step}$ varying within $5 - 15\ eV$. In majority of the runs, where fit program was able to give meaningful values for 6 parameter fit with step function, the value of m_ν^2 turned out to be about zero within fit errors. An impossibility to obtain definite minima of χ^2 in the 6-parameter fit for some run was connected with strong correlation of ΔN_{step} and m_ν^2 when step position is too close to endpoint. For such run the step parameters were obtained putting $m_\nu^2 = 0$.
Changeable positions of the step with respect to end point energy from run to run for the first look was evidence for some systematics . The situation become more enigmatic when the values of $E_0 - E_{step}$ were plotted versus calendar time of corresponding run. The plot is given in Fig. 5. Very surprising feature of it turned out to be the possibility to describe the time dependence of the step position by a sinusoidal curve.

The period of the fitted sinusoid proved to be equal to 0.496 ± 0.003 years, mean value of the position $10.4\ eV$ and amplitude $4.35\, eV$. Dependence of χ^2 on the value of the period obtained in the fit with variable mean value, amplitude and phase of

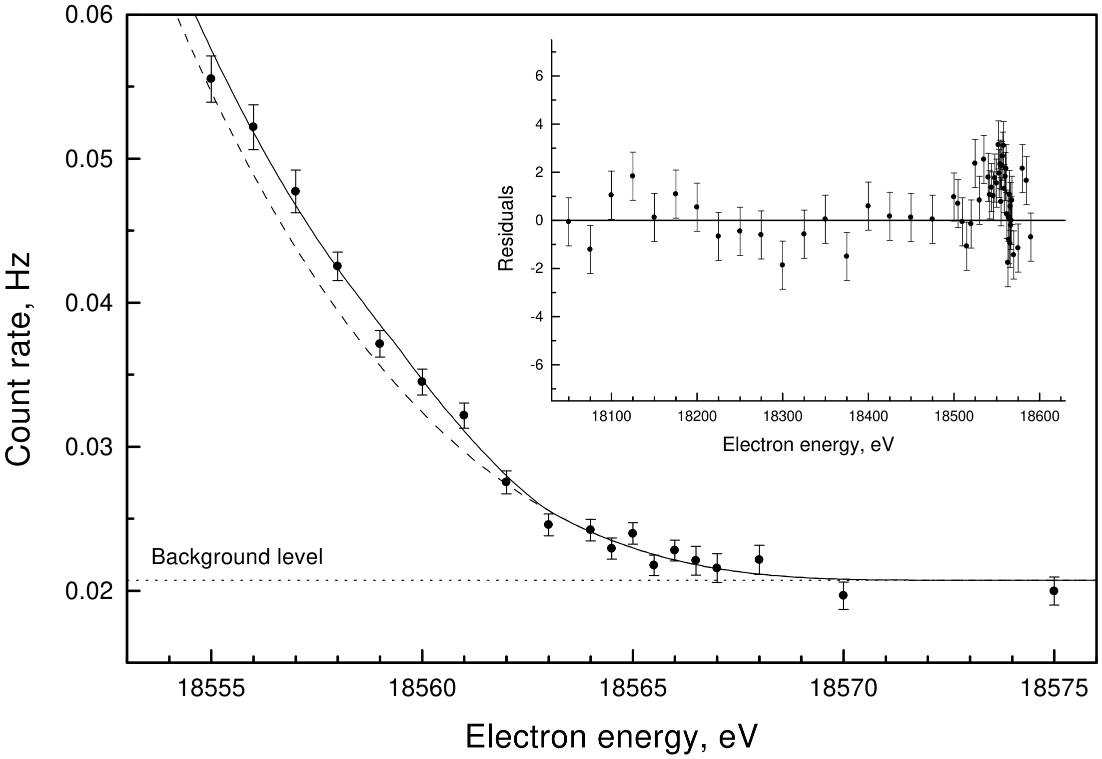

Fig. 3. Part of experimental spectrum near the end-point. Solid line is the fitted theoretical spectrum with step function. Dotted line is theoretical spectrum with subtracted step function. Upper right corner: spectrum of residuals for all measured part of spectrum. Residuals are $(N_{exp} - N_{theor})/\sigma$, where N_{exp} is the same as dotted line in previous plot, σ is standard deviation in each point.

the sinusoid is given in Fig. 6. It is seen that half a year period is the most probable one.

Combining data of all the years in one year plot confirm that the variation of the step position have biseasonal character (see Fig. 7). It is whorth while to mention that set of data given in Fig. 5 and Fig. 7 is somewhat different from early reported [9]. Difference consists mainly in larger errors of $E_0 - E_{step}$ caused by fitting a parabola to the projection of χ^2 minima instead of direct use of values produced by MINUIT fit program.

More peculiar proved to be the plot of step size values given in Fig. 8. The data obtained before the last run (R98,3) roughly agreed, at least for the first maximum, with the half year period with larger step size corresponding to larger distance from end-point. The last measurement, being relatively short, resulted in almost 3 times larger step size and $E_0 - E_{step}$ somewhat below the sinusoid fitted to previous data. This outburst may signify that step phenomenon, if not to consider it like some

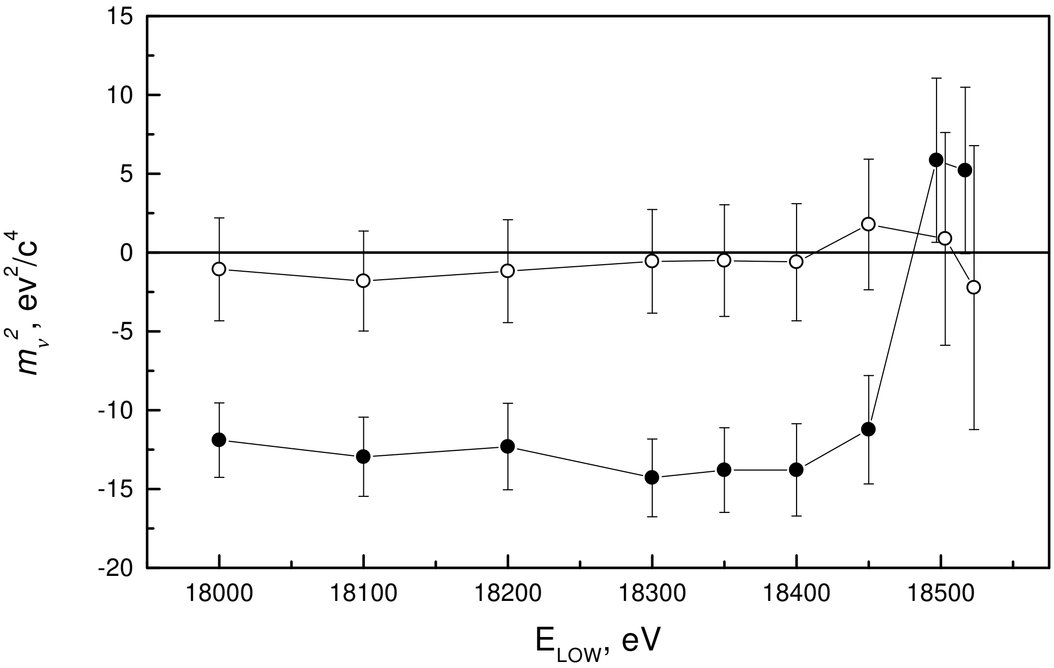

Fig. 4. Dependence of m_ν^2 on E_{low} for sum of data Run94, 96, 97(2), 98. Closed circles - fit without step function (4 parameter fit) Open circles - fit with step function (6 parameter fit).

apparature effect, may fluctuate in size with characteristic time less then a month, at the same time the position being close to sinusoid. This may be confronted with last measurement of Mainz group, where they did not find the step effect a few weeks earlier [26)]. Unfortunately Troitsk set-up did not run this time.

Of course present set of data needs to be sufficiently extended. In particular absence of measurement within the period July - December and absence of continuous measurement during all the year make possible to fit more complicated periodic curve but with the half year component as dominant one.

At the moment it seems to be impossible to propose any "customary" explanation of this phenomenon. The proximity of the oscillation period of the step (bump) to half period of Earth circulation around the Sun and other features of it allows to remind an old speculation about an effect produced by capture of the cosmological degenerated neutrino by tritium atoms with emission of almost monochromatic electrons [11)]. 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

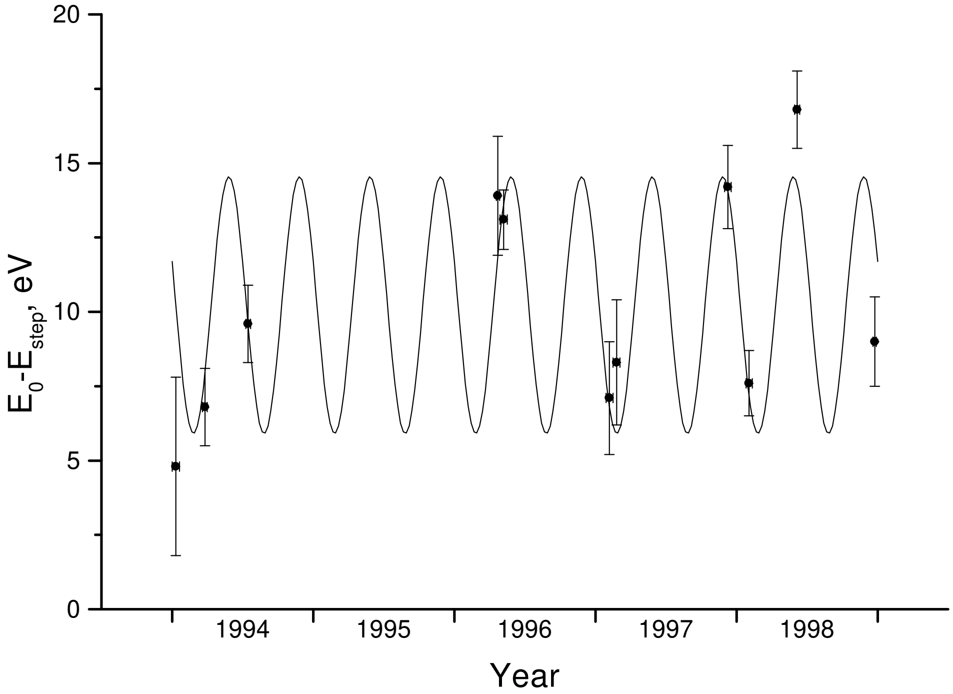

Fig. 5. The step position dependence on the calendar time of measurements. Parameters of the fitted sinusoid are: Period $0,496 \pm 0,003$ year, mean value $10,4 \pm 0,4\,eV$, amplitude $4,3 \pm 0,55\,eV$, phase $2,6 \pm 0,23\,rad$.

as $0.5 \cdot 10^{15}\ \nu/cm^3$, that is 10^{13} times more than generally accepted average density of relic massless neutrino.

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. In the case of binding energy changing over the cloud,the Earth in its movement produces the periodical modulation of binding energy and correspondingly position of the step. It is interesting to point out that this hypotetical binding energy assumed as $V = E_0 - E_{step} + E_{Fermi}$ where E_{Fermi} is calculated from the step size, being plotted as in Fig.2 provides somewhat better fit for sinusoid with $\chi^2 = 5.3$ for 7 dof in comparison with 11.7 for previous fit. In order to explain the half year modulation period one may suppose that the neutrino cloud has shape of flattered disc with axis of symmetry inclined with respect to normal direction to Ecliptic plane.

The size of neutrino cloud in this case must be comparable with Earth orbit and it does not contradict to average density of relic neutrino in the Universe. Of course this explanation of step phenomenon is extremely speculative and may be considered

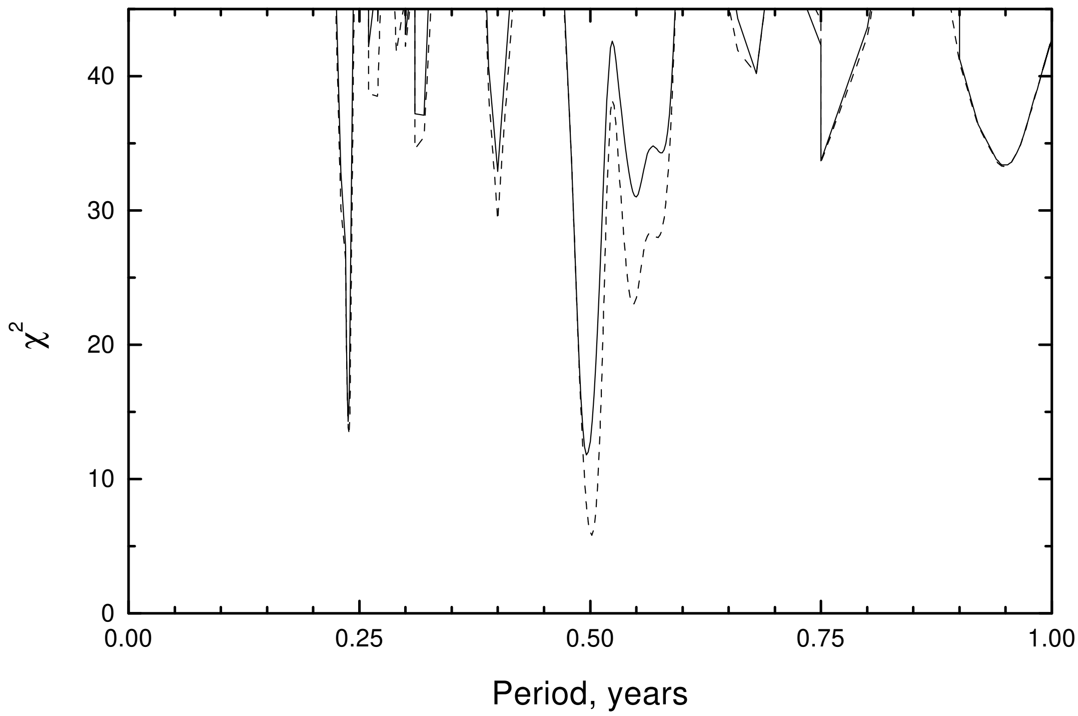

Fig. 6. The χ^2 dependence on the period of sinusoid fitted to step position plot versus calendar time of measurement. Period value was scanned and 3 other parameters were left variable. Solid line corresponds to all the run fit and dotted line to that with the last run (December 1998) being omitted.

only for stimulation of further experiments.

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

6. 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

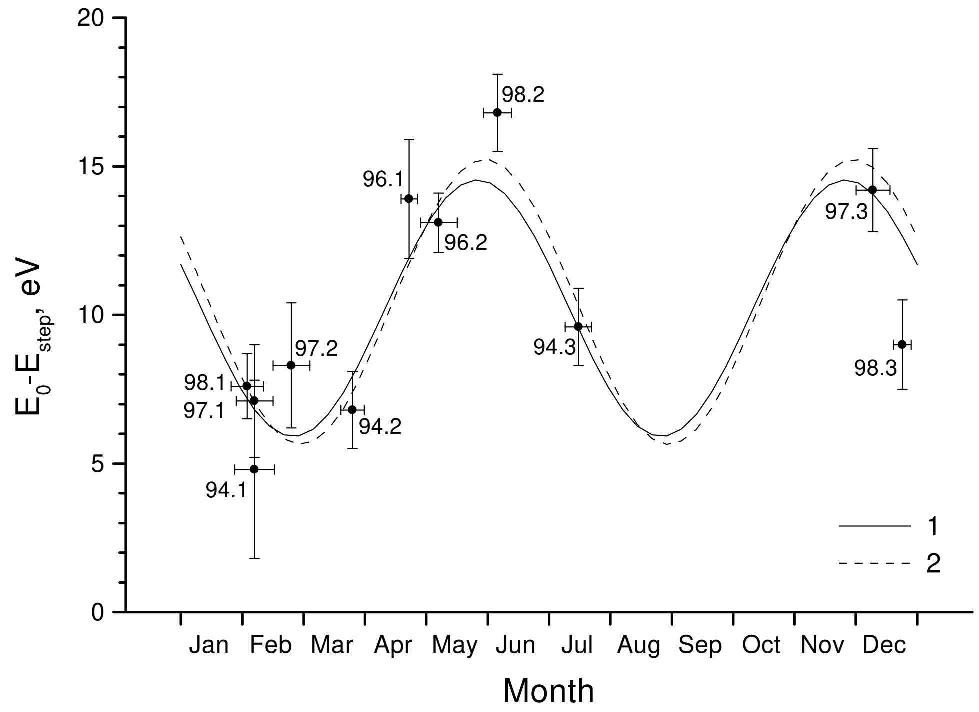

Fig. 7. The plot of step positions versus time of the year. Fitted sinusoid is the same as in Fig. 2, but with the period being 0.500 year. Horizontal bars are length of the run. Indexes of points are: year and number of the run.

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 that is linearly increasing with $E - E_0$. 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, correlates 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.A possibility to distinguish neutrino mass effect from step strongly decreases with proximity of step position to end-point due to correlation of their parameters. Such correlation made impossible to use data of Run97(1) and 98(1) for analysis for the neutrino mass inspite of its good statistics. Systematical errors besides uncertainty caused by step function 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, uncertainty

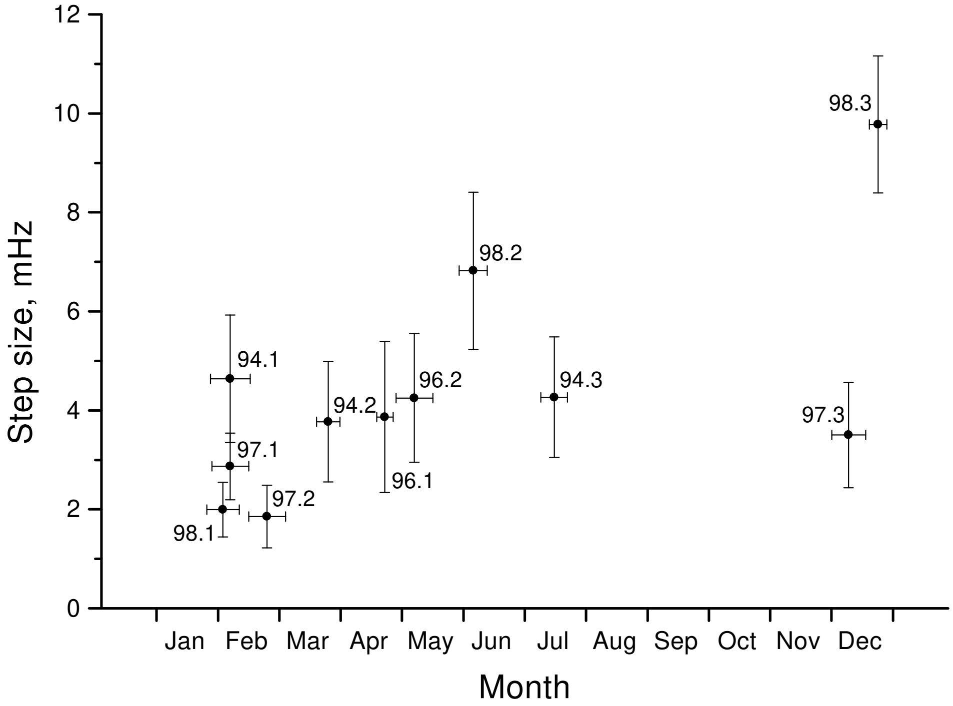

Fig. 8. Plot of step size versus time of the year. All the size values are reduced to the same intensity of source.

of excitation and ionization parts of the inelastic cross section, dead time, and influence of high exited FSS part. A remarkable property of the total systematic error from these factors is its reduction when E_{low} comes nearer to end-point E_{low}, opposite to it the systematics connected with apriory unknown function uncertainty increases when E_{low} comes closer to end-point, that is automatically taken into account in the fit procedure. 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:

$$1994 \;\; m_\nu^2 = -2.7 \pm 10.1_{fit} \pm 4.9_{syst} \; eV^2/c^4 \tag{2}$$

$$1996 \;\; m_\nu^2 = +0.5 \pm 7.1_{fit} \pm 2.5_{syst} \; eV^2/c^4 \tag{3}$$

$$1997(2) \;\; m_\nu^2 = -3.2 \pm 4.8_{fit} \pm 1.5_{syst} \; eV^2/c^4 \tag{4}$$

$$1998 \;\; m_\nu^2 = -0.6 \pm 8.1_{fit} \pm 2.0_{syst} \; eV^2/c^4 \tag{5}$$

The combined value in quadrature:

$$m_\nu^2 = -1.9 \pm 3.4_{fit} \pm 2.2_{syst}\ eV^2/c^4 \tag{6}$$

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

$$m_\nu < 2.6\ eV/c^2; \tag{7}$$

7. Mainz experiment.

The experiment on the search for the neutrino mass in Mainz University has a number of different features in comparison with "Troitsk ν-mass". Most important is use of the source of tritium frozen onto substrat cooled down to 2.5K. Early measurement reported in [2] demonstrated rise of the spectum to low energy and correspondingly rising of negative m_ν^2 amounting to $-117\ eV^2$. Another problem was penetration of tritium into spectrometer due to position of the source in the first solenoid.The background proportional to source strength limited maximal activity of the source. The low energy rise of the spectra was found to be due to T_2 film roughness. Lowering of substrate temperature to 1,8K helped to avoid effect of low energy rise of negative m_ν^2. Penetration of tritium to spectrometer was essentially supressed by means of additional bent superconducting magnetic channel connecting source area with spectrometer.It allowed to rise the source activity and counting rate almost by an order of magnitude without increasing of the background. Unfortunately increasing of source thickness revealed the effect of selfcharging of the source that deteriorate energy resolution and provide some uncertainty in the fit. At present data of 4 runs carried out in 1997 and 1998 were analyzed. The results presented at WIN99 [26] are free from low energy anomaly. The last 2 runs produced data with precision being comparable with Troitsk data. The analysis of July 98 run gives evidence for the step effect in agreement with Troitsk data, but in another run of November 1998 Mainz group did not find step effect. It may be considered as a result of the short period variation of the step effect which were mentioned above.

8. Further study of the effects in tritium beta-spectrum.

Further investigation of the bump-like anomaly and the neutrino mass search at the level about 1 eV/c^2 require major improvement of trituim beta-spectrometry. One of the obvious way is enlargement of existing set-up by a few times. The other way could be the development of a differential spectrometer with the resolution and luminousity on a par with the integral one. Differential spectrometer allows better study of local anomalies in continuous spectra and will serve both for search of the kinks from heavy neutrino and above mentioned tasks. In the report [9] a new type of differential spectrometer designed on the principles of adiabatic motion of electrons in electric and magnetic fields was proposed.

The spectrometer consists of the integral electrostatic spectrometer with adiabatic magnetic collimation with the central part which is lengthed and bent on 180 or 360 degree. Input part of the spectrometer cuts electrons with the energy below the potential of the central electrode with relative spread less than $E_0 \cdot H_{min}/H_0$.

At the central region of the spectrometer the electrons fly in the weak magnetic field with their moments being lined up along the magnetic lines and the energy being $E_{in} - e \cdot V_0$, where E_{in} is the initial electron energy and V_0 is the potential of the analyzing electrode. Magnetic field in the central part has toroid like shape as well as central electrode. Electrons moving adiabatically inside the toroidal electrode are in zero electrostatic field and drift perpendicularly to the toroidal plane owing to well known transverse drift. The magnitude of the drift with respect to the magnetic force lines depends on the velocity of the electron and rapidly increases with the electron energy. Although the drift is not big, mounting inside the toroidal electrode a multislot collimator with the slots parallel to the toroid plane allows to cut electrons with the drift more than the width of a slot.

One can expect some increase of the background due to bombardment of the collimator ends by ions which are accelerated in the detector part of the spectrometer. To avoid this a slot mask will be mounted on the detector so that the adiabatical images of the end plates of the collimator are projected onto the covered regions of the detector.

Thus only electrons with the energy not more than several eV inside the toroidal electrode can reach the detector. Electrons with higher or with very low energy will die on the collimator plates.

Luminosity of such spectrometer will depend on the cross section of the central electrode and on the dimension of the tubes in the tritium source. The optimal parameters of the spectrometer should be studied in details but it seems quite possible to construct a device with resolution about 2 eV and luminosity 1 cm^2. This could give substantial improvement of all the tritium spectrometry.

9. Acknowledgments

This work was partially supported by the Russian Foundation for Basic Research (grants 3903 and 18633a), by Program for Fundamental Nuclear Physics and INTAS-RFBR grant 95-819. The author is also very thankful to Alexander-von-Humboldt Foundation for a grant for Scientific Research.

10. References

1) A. I. Belesev et al., Phys. Lett., B 350(1995)263.

2) Ch. Weinheimer et. al., Phys. Lett., B300(1993) 210.
3) V. M. Lobashev and P. E. Spivak, Preprint INR P-0291, Moscow (1983).
4) V. M. Lobashev and P. E. Spivak, Nucl. Instr. Methods A 240 (1985) 305.
5) V. M. Lobashev et al., Nucl. Instr. Methods A 238(1985) 496.
6) A. Picard et al., Nucl. Instr. Meth., B63(1992)345.
7) V. M. Lobashev et al., Proceedings of the International Conference NEUTRINO-96, Helsinki, Finland; June 13-19, 1996, World Scientific p.264-277.
8) V. M. Lobashev et al., Proceedings of WIN-97, Capri, June 22-28, 1997.
9) V. M. Lobashev, Progress in Particle and Nuclear Physics 40, 337-351,(1998).
10) S. Jonsell and H. Monkhorst, Phys. Rev. Lett. 76 (1996) 4476.
11) G. J. Stephenson Jr., T. Goldman and B.H.J.McKellar, Int. Jour. Mod. Phys. A, Vol. 13, No. 16, (1998) 2765-2790.
12) R. N. Mohapatra and S. Nussinov, Phys. Lett. B 395 (1997) 63-68.
13) T. Hsu and J. L. Hirshfield, Rev.Sci.Instrum., Vol. 47, No. 2, 1976, p. 236-238.
14) G. Beamson, H. G. Porter and D. N. Turner, J. Phys. E. Sci. Instrum. Vol. 13, 1980, p. 64-66.
15) ALEPH Collaboration, Eur.Phys.J.C2,395-406 (1998).
16) K.Assamagan et al.,Phys.Rev.D ,53 (11),6065-6077,(1996).
17) B.Jeckelmann et al.,Phys.Lett. B335,326,(1994).
18) D.Anagnostopoulos et al.,PSI Annual Report 1996/Annex I, p.19.
19) V. A. Lubimov et al., Phys. Lett., B 94 (1980) 266.
20) E. Holzschuh et al., Phys. Lett., B 287 (1992) 381.
21) H. Kawakami et al., Phys. Lett. B 256 (1991) 105.
22) . G. H. Robertson et. al., Phys. Rev. Lett., 67 (1991) 957.
23) W. Stoeffl and D. J. Decman, Phys. Rev. Lett. 75 (1995) 3237.
24) E. Tret'yakov Izvest. Akad. Nauk. SSSR, Ser. Fiz. 39 (1975) 583.
25) T. Goldman and G. J. Stephenson Jr., hep-ph/9309308.
26) J.Bonn, Report at WIN((, Cape Town 24-28 January 1999.