

First results of the Troitsk experiment on the search for electron antineutrino rest mass in tritium beta-decay

S.N.Balashov §, A.I.Belevsev †, A.I.Bleule †, E.V.Geraskin †, A.A.Golubev †, N.A.Golubev †,
O.V.Kazachenko †, E.P.Kiev †, Yu.E.Kuznetsov †, V.M.Lobashev †, B.M.Ovchinnikov †,
V.I.Parfenov †, I.V.Sekachev †, A.P.Solodukhin †, N.A.Titov †, I.E.Yarykin †, Yu.I.Zakharov †
P. E. Spivak §†

† Institute for Nuclear Research of Russian Acad. of Sciences, Russia

§ Institute for Nuclear Physics - R.S.C. "Kurchatov institute", Russia

Abstract

First results of investigation of tritium beta-spectrum near its end-point, carried out in INR RAS - INP("KI") (Troitsk) experiment, are presented. Experimental set-up includes an integral electrostatic spectrometer with adiabatic magnetic collimation and a gaseous tritium source of electrons. Fit of data gives value for m_ν^2 equal to $-18 \pm 6 eV^2$. Study of beta-spectrum in the region $7 - 15 eV$ below its end-point provides indication that the effect of negative m_ν^2 may be explained by a spike-like (in differential spectrum) structure corresponding integrally to about 6×10^{-11} of total decay probability. The obtained upper limit for m_ν equals $4.5 eV$ at 95% C.L.

We report here first results of the experiment on search for electron antineutrino rest mass in tritium beta decay. The experiment is being carried out at the Institute for Nuclear Research of Russian Academy of Sciences in the city of Troitsk of the Moscow region. The main features of the experiment are the use of integral electrostatic spectrometer with adiabatic magnetic collimation and gaseous tritium source of electrons. The main ideas of this experiment were first proposed in [1]. Some description of the experimental set-up was given in [2] and will be published in detail elsewhere. Spectrometer device based on similar principles was independently developed in Mainz, the main distinction being the use of frozen tritium source of electrons [3]. In our measurements the energy resolution was adjusted to be equal to $3.7 eV$ (FW) at $18.6 keV$. The spectrometer luminosity was $0.27 cm^2$ and the effective surface density of $T_2 + TH + H_2$ was maintained

at the level of about $1 - 1.7 \times 10^{17} atoms/cm^2$.

Measurements of spectra were carried out changing the spectrometer potential by steps in the range from $18175 V$ to $18770 V$.

The measurement of the spectrometer resolution function and energy losses in tritium was made using an electron gun with photoemission induced by ultraviolet lamp. The accuracy of the energy losses factor measurement was estimated as 5%.

The fitting procedure at first step included 4 free parameters: normalization factor, the background, the end-point energy, and m_ν^2 . The lower limit of the fit interval of the spectrum (E_{low}) was changed from $18175 eV$ to $18500 eV$ (for fitting results see table 1). Backward scattering and deflection efficiency energy dependence were not included into the analysis because it was shown that their influence on the result of fit is insignificant.

It is seen from the table that value of m_ν^2 is definitely

† Deceased.

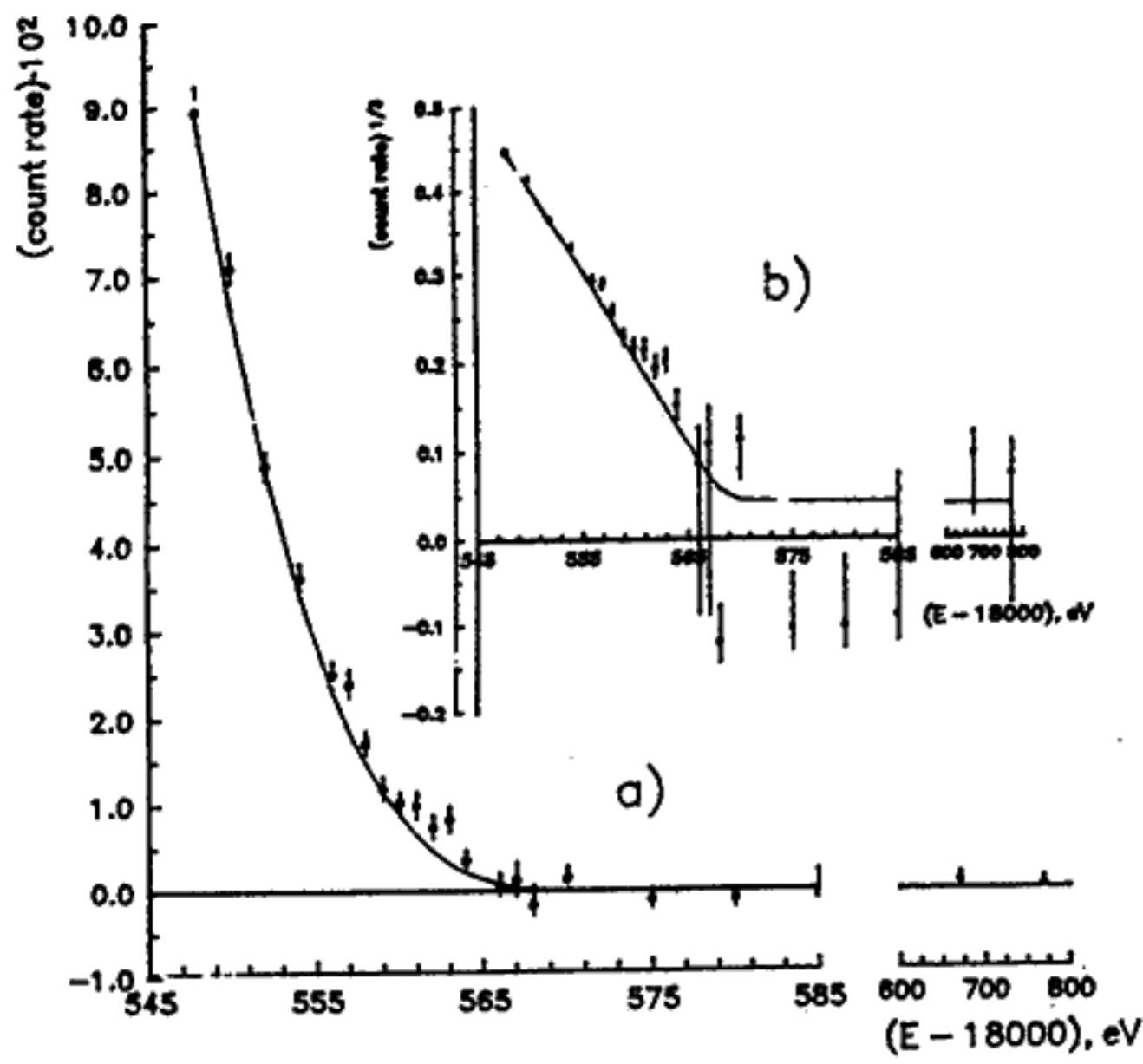


Figure 1. Part of the tritium spectrum (a) and Curie-plot (b) near the end point.

negative for all E_{low} and there is a rise of negative value both at the lowest and highest E_{low} . The source of the first one is an increase of intensity of about 1% at 18175 eV revealing when spectrum fitted with $E_{low} > 18350 eV$ is extrapolated down to 18175 eV, similar effect was observed in [3]. Formally, it is possible to fit this increase by β -decay transition to the some "missed" final state with excitation energy 100 – 150 eV and probability of a few percent.

E_{low} (eV)	18175	18300	18350	18400	18450	18500
m_ν^2 (eV ²)	-37.5 ±4.3	-19.3 ±4.8	-20.2 ±5.3	-18.6 ±6.1	-25.5 ±7.3	-35.7 ±10.2
E_0-18 KeV	573.15 ±0.08	573.60 ±0.10	573.55 ±0.11	573.60 ±0.12	573.35 ±0.18	572.95 ±0.38
$\frac{\chi^2}{d.o.f}$	$\frac{83.0}{42}$	$\frac{39.70}{39}$	$\frac{39.30}{37}$	$\frac{37.40}{35}$	$\frac{33.50}{33}$	$\frac{30.00}{31}$

Table 1. Results of the fit for m_ν^2 and E_0

Examination of the spectra presented in Fig. 1 draws attention to the group of points below 18564 eV, that is about 7 eV below the end point. These several points seem to form some step starting from about 18563 eV and extending to lower energy that is looking like a spike in differential spectra. Taking

into account this observation, we made an attempt to check possible connection between this step-like structure and the effect of negative m_ν^2 by subtraction of step-like functions starting at 18563 eV with different magnitudes. Fitting procedure described above was carried out for the each step magnitude. It proved to be that the dependence of χ^2 on the magnitude of the step clearly exhibit a parabolic shape with the minimum at about 2.5 – 3 mHz. The m_ν^2 -dependence on the magnitude of the step forms more or less linear function with all the graphs crossing the axis corresponding to $m_\nu^2 = 0$ around the point 2.5 mHz.

The existence of the minimum of χ^2 just around $m_\nu^2 \approx 0$ appears to be an important indication of connection of this step-like structure in original spectrum with the phenomenon of negative m_ν^2 for the fitting interval with $E_{low} > 18350 eV$.

If we postulate $m_\nu^2 = 0$, leaving the other parameters free, we obtain step magnitude being equal to $2.61 \pm 0.63 mHz$ corresponding to B.R. = $(6.3 \pm 1.5) \times 10^{-11}$ of the total decay rate.

With m_ν^2 and step magnitude taken as a free parameters we may obtain upper limit for m_ν^2 . Step magnitude and m_ν^2 are strongly correlated and this leads to a significant increase of upper limit for m_ν^2 . For most restrictive case (E_{low} equals 18350 eV) one can deduce the upper limit

$$m_\nu^2 < 20 eV^2, \text{ or } m_\nu < 4.5 eV \text{ at } 95\% \text{ C.L.}$$

This limit is essentially lower than those published up to now and involves a new kind of systematics which was not seen previously.

We do not include other uncertainty factors like electron energy loss inaccuracy because its influence on m_ν^2 limit is relatively small.

The spike-like structure in tritium beta spectrum of B.R. $\sim 10^{-10}$ could not be seen in the previous experiments [3, 4] due to insufficient statistical accuracy and cannot be reasonably understood on the basis of usual beta-decay processes. Admixture of some unknown radioactivity was rejected by special control experiment.

At the moment it seems to be early to discuss some exotic explanations of spike-like effects in tritium decay until this phenomenon is studied more carefully. It is possible in near future to improve both statistical and systematical accuracy of this experiment at least by a few times thus making the situation clearer.

References

[1] V.M. Lobashev and P.E. Spivak, Moscow preprint: INR P-0291 (1983); and Nucl. Instr. Meth. **A240** (1985) 305.
 [2] S. Balashov et al., Proceedings of WEIN-89 (Montreal 1989), p.295 (Edition Frontieres).
 [3] Ch. Weinheimer et al., Phys. Lett. **B300** (1993) 210.
 [4] R.G.H. Robertson et al., Phys. Rev. Lett. **67** (1991) 957.