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NEW MEASUREMENTS OF THE ANTINEUTRINO–SPIN ASYMMETRY IN BETA DECAY OF THE NEUTRON AND RESTRICTION FOR MASS OF W_R

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In this work we report on new results of measurements of neutron antineutrino–spin asymmetry coefficient B in beta decay of polarized neutrons. This work has been carried out on the polarized neutron vertical channel of the WWR–M reactor at PNPI (Gatchina). From results of measurements of the experimental asymmetry, $x = BP = 0.6617 \pm 0.0044$, and from results of measurements of the beam polarization, $P = (66.88 \pm 0.22)\%$, the value of the antineutrino spin asymmetry coefficient was obtained: $B = 0.9894 \pm 0.0083$. This allows us to place restrictions on M_{W_R}: $M_{W_R} > 282$ Gev/c^2 (90% C.L.).

Precise measurements of neutron beta decay parameters allow one to test the standard model of weak interactions. Recently, the accuracy of measurements of the neutron lifetime and electron–spin asymmetry have been improved considerably. This allows one to determine, with good accuracy, the vector and axial vector coupling constants of weak interactions. At the same time, the vector coupling constant G_v obtained from neutron data is in poor agreement with G_v obtained from superallowed nuclear $0^+ \to 0^+$ transitions (Refs. [1–3]). Analysis of this discrepancy together with data from ^{19}Ne in the frame of the left-right model of weak interactions gives the possibility to obtain the region of mass of W_R of 230 Gev/c^2 (Refs. [2,3]). This is in contradiction with restrictions from muon decay and restrictions from direct searches for additional vector boson W' (Refs. [4, 5]). Confirmation of this restriction directly from antineutrino–spin asymmetry of neutron beta decay seems possible at accuracy of measuring better than 1% (Ref. [3]).

This work has been carried out at the vertical channel of cold polarized neutrons at the WWR-M reactor. The neutron capture flux density is 6×10^8 n/cm^2/sec. The maximum wavelength in the spectrum is 4.2 Å.

The scheme of the measurement was proposed in Ref. [6], but now is sufficiently modernised. Measurements of momentum and angle of escape of the undetected antineutrino are possible due to detection of coincidence of electron and recoil proton and due to determination of their momentums. A kinematic diagram of beta decay is shown in Fig. 1. From the well known energy of decay and

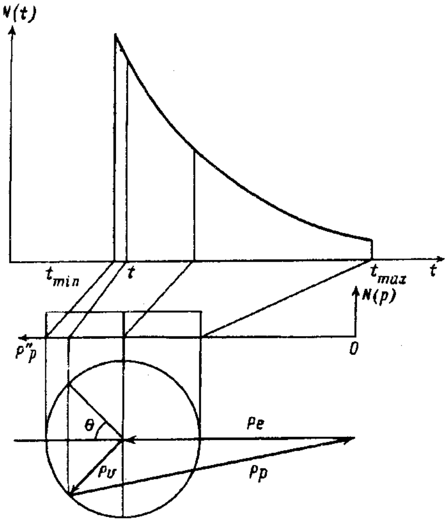

Fig.1.

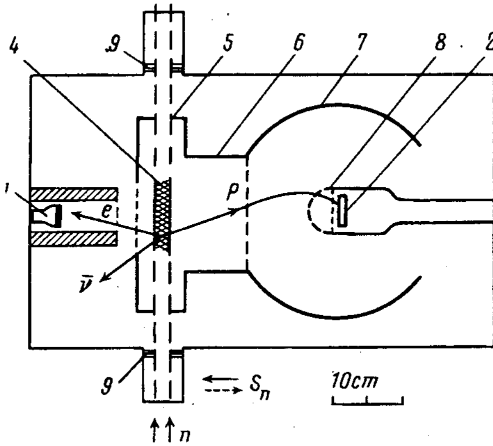

Fig.2.

Fig.1. The momentum diagram of neutron decay products and time–of–flight spectrum of protons for the ideal conditions

Fig.2. Experimental setup: *1* – electron detector; *2* – proton detector; *3* – chamber; *4* – decay region; *5* – cylindrical electrode; *6* – TOF cylinder; *7* – spherical electrode; *8* – spherical grid; *9* – **LiF** diaphragm

from measurement of electron energy, the energy taken by the antineutrino can be calculated with accuracy better than 0.75 keV which is the maximum proton recoil energy. For a known electron momentum, all possible values of antineutrino momentum lie on a sphere of radius $P_{\tilde{\nu}} = (E_0 - E_e)/c$, where $P_{\tilde{\nu}}$ is antineutrino momentum, E_0 is the total kinematic energy of decay, and E_e is the electron energy. The measurement of parallel projection of proton momentum with respect to electron momentum allow us to determine the antineutrino escape angle and, as a result, to reconstruct the beta decay event. The determination of $P_p^{||}$ can be done by the time of flight method.

The events detected in this experiment can be written in the form of a matrix of coincidence with coordinates E_e and t_p for two opposite directions of beam polarization. The count rate of events for each cell of this matrix can be calculated taking into account Fermi function f(E) and correlation coefficients of beta decay:

$$N_{ik}^{\pm} = f_i(E)[1 + a\frac{v_i}{c}(\cos\theta_{e\tilde{\nu}})_{ik} \pm PA\frac{v_i}{c}\cdot(\cos\theta_{\sigma e})_{ik} \pm PB(\cos\theta_{\sigma\tilde{\nu}})_{ik}], \tag{1}$$

This yields the experimental asymmetry:

$$X_{ik} \equiv \frac{N_{ik}^{+} - N_{ik}^{-}}{N_{ik}^{+} + N_{ik}^{-}} = \frac{PA\frac{v_i}{c}(\cos\theta_{\sigma e})_{ik} + PB(\cos\theta_{e\tilde{\nu}})_{ik}}{1 + a\frac{v_i}{c}(\cos\theta_{e\tilde{\nu}})_{ik}}, \tag{2}$$

and finally:

$$PB = \frac{[X_{ik}(1 + a\frac{v_i}{c}(\cos\theta_{e\tilde{\nu}})_{ik})] - AP\frac{v_i}{c}(\cos\theta_{\sigma e})_{ik}}{(\cos\theta_{\sigma\tilde{\nu}})_{ik}}, \tag{3}$$

where a, A and B are coefficients of electron–antineutino, electron–spin, and antineutrino–spin asymmetries, P is the degree of neutron polarization. The subscripts i and k correspond to definite interval of electron energy E_i and to definite interval of time of flight for proton t_k. For determination of B it is necessary to know the beam polarization and calculated values of $\frac{v}{c}\cos\theta_{e\tilde{\nu}}$, $\frac{v}{c}\cos\theta_{\sigma e}$ and $\cos\theta_{\sigma\tilde{\nu}}$. The values of correlation coefficients a and A can be taken from previous experiments (Ref [7, 8]). It must be noted that the terms with the coefficients a and A are small (< 0.1), and thus its errors are not important for the total error of PB.

A necessary part of this measurement is the correct calculation of mean cosine values: $\frac{v}{c}\cos\theta_{e\tilde{\nu}}$, $\frac{v}{c}\cos\theta_{\sigma e}$ and $\cos\theta_{\sigma\tilde{\nu}}$. To calculate these values a special Monte Carlo model of the beta decay process inside our apparatus was prepared. This model includes all the necessary geometrical parameters of the chamber, responses of the electron and proton detectors, distribution of neutron intensity inside the beam (this was measured in a separate experiment), shape of the electron spectrum in the form of the Fermi function and characteristics of the amplitude–digital (ADC) and time–digital (TDC) converters. Also, the real distribution of electric field inside the apparatus was taken into account.

The scheme of installation is shown on Fig.2. The decay region *4* is defined by means of a special diaphragm in front of the electron detector. The coincidences of signals of electron *1* and proton *2* detectors, located on the both sides of the decay region, are registered with opposite directions of neutron polarization. The electron detector *1* is a photomultiplier with a plastic scintillator (diameter 75 mm and thickness 3 mm). The characteristics of this detector – energy resolution and fraction of backscattering of electrons – were determined in Ref.[8] by means of a magnetic beta spectrometer.

Decay protons which go through the time of flight cylinder *6* with their initial velocities are later accelerated and focused onto the detector *2* by an electric field with potential 25.6 kV applied between a spherical electrode *7* and spherical grid *8*. The proton detector is the assembly of two microchannel plates. The diameter of the detector is 65 mm. The detector allowed us to determine the time of flight of each proton with an accuracy of 10 nsec.

The entire chamber is surrounded with three pairs of current carrying frames for compensation of the earth's magnetic field and provide guiding magnetic field in chamber which is equal to 0.5 oersteds. The residual earth's field is not more than 0.01 oersteds. The changing of direction of polarization is produced by a radio frequency (RF) flipper. To obtain the additional symmetrization of the measurements the guiding magnetic field of installation together with the magnetic field of the flipper were changed from time to time.

The data acquisition system was organized by the following way. The signal from the electron detector gives a start for the proton time of flight measurement and simultaneously is used for measuring the electron energy with help of ADC. The proton signal gives a stop for time of flight measurement with help of TDC. For exact determination of background, the method of delayed coincidence is used and the measurement of background takes place simultaneously with measurement of the coincidence signal and with the same electronic scheme.

The total data acquisition time was about 93 hours. The total number of decay events was 393057. The signal to noise ratio in the area under the time of flight spectrum was 1.5:1.

At the beginning and end of every run the energy detector was calibrated. This was done to correct for possible gain shifts of the photomultiplier. Calibrations were carried out with the help of a calibrated electron sources ^{113}Sn and ^{137}Cs

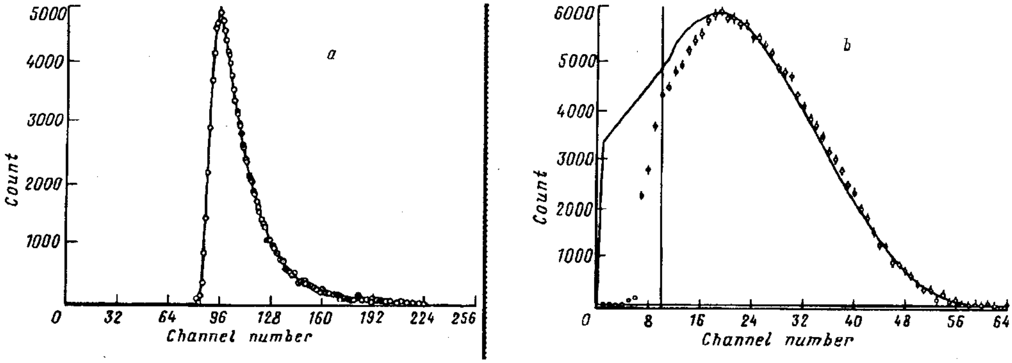

Fig.3. Comparison of experimental and simulation spectrums.
a – time of flight spectra (1 channel is 10 nsec), *b* – energy spectra (1 channel is 10.75 keV, low threshold - 10 channel - corresponds to 268 keV), – – computer simulation, o – experiment

Comparisons of experimental results and calculations for both time and energy spectra are shown in Fig. 3*a* and 3*b*. The time of flight proton spectrum is integrated over energy and polarization states while the energy spectrum is integrated over time and polarization states. One can see that the agreement between experimental and calculated time of flight spectra is very good and $\chi^2 = 1.15$. The agreement of the energy spectra in the region of low energy is poor, however analysis of the experimental data shows that this does not produce an influence on the final result.

For treatment of the experimental data it is rather important that the theoretical and experimental time of flight spectra for each energy coincide. A special procedure of the analysis was organized to remove the effects of possible nonlinear discreapancy and possible shift between experimental and calculated time scales. For this purpose both the time spectra were divided into a number of parts with equal intensity . In this case every parts of spectra corresponds to quite definite mean values of cosines. This method allowed to obtain dependence of B on $\cos\theta_{\sigma\bar{\nu}}$ and completely exclude the problem of shift and nonlinear discreapancy of the time scales.

The results of treatment of experimental data in the form of dependence of constant PB on $\cos\theta_{\sigma\bar{\nu}}$ are presented in Fig. 4. The average value $PB = 0.6617 \pm 0.0044$ and $\chi^2 = 0.78$.

Analysis of possible systematic errors of this experiment was done by the method of variation of model parameters in the frame of uncertainty of these parameters. These parameters are: resolution of electron detector, size of energy channel, placement of zero in energy scale, the value of the backscattering tail, geometrical sizes and uncertainties in knowledge of correlation coefficients a and A. This analysis gives an estimation of the possible systematic error of our result equal to ± 0.0037. The main part of this error deals with the low resolution of electron detector.

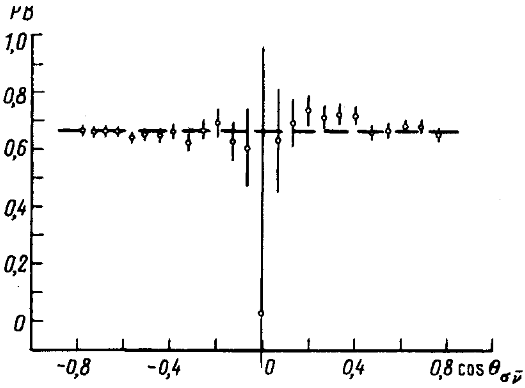

Fig.4.

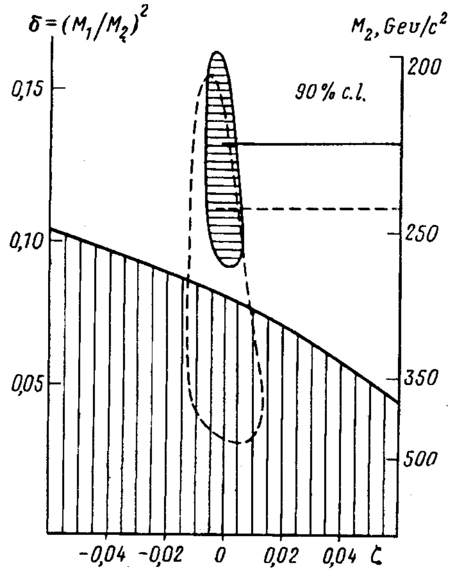

Fig.5.

Fig.4. Dependence of B on $\cos\theta_{\sigma\bar{\nu}}$. The average value $PB = 0.6617 \pm 0.0044$ and $\chi^2 = 0.78$

Fig.5. The restriction for the left–right model from different experimental data. The horizontal shaded region – from the neutron β–decay, nuclear $0^+ \to 0^+$ transitions and from the decay of ^{19}Ne (the region shown by the dotted line – the same without data from Ref. [8]). The restriction from the present measurement – the vertical shaded region

The polarization of neutron beam was measured by a new method of precise determination of beam polarization. This me- thod and its result are described in detail in Ref. 9. In these measurements, the behavior of spectral space and angular distribution of beam are taken into account. The polarization has been averaged with the spectrum of time of flight through the installation and also the spectral dependence of flipper efficiency has been taken into account. The measurements of polarization have been carried out simultaneously with the measurement of B. As a result of these measurements the following value of polarization was obtained:

$$P = 0.6688 \pm 0.0022$$

Using the value of PB and P, the following value of the antineutrino–spin asymmetry was obtained:

$$B = 0.9894 \pm 0.0083$$

This result has an accuracy which is 4.2 times better than the previous measurement (Ref.[10]).

Using the obtained result it is possible to give the restriction on the mass of the W_R from the neutron β–decay. The antineutrino–spin asymmetry is not sensitive to influences from the strong interactions, from renormalization of the axial vector constant and from influences of radiative corrections. In spite of available discrepancy in determination λ ratio from different experiments, the value B are predicted in the frame of $V - A$ theory equal to 0.988 with accuracy

0.001. In the frames of the left-right model (at zero mixing angle) the value $B = (1 - 2\delta^2)B_{V-A}$ where δ is the squared ratio of left and right boson masses. Because deviation of predicted and measured values is not observed with accuracy 0.0083, the restriction for M_{W_R} is amount for 282 GeV/c^2 (90% CL). More complete analysis of restriction from this experiment is presented on the plane squared mass ratio (δ) and mixing angle (ζ) (see Fig. 5). On this figure analysis of experimental data of neutron lifetime, neutron electron spin asymmetry, lifetime for $0^+ \rightarrow 0^+$ transitions, and also lifetime and asymmetry in ^{19}Ne which demonstrate the origin of mass about 230 GeV/c^2 are presented. The results of our experiment fails to confirm the existence of this island directly from neutron beta decay.

The possibility of this method is not realized in full scale here because the time of collection of statistics amounted to only 93 hours. As systematic errors are not observed in this experiment and experiment can be improved by prolongation of collection of statistics. Apparently the restriction of statistical accuracy in this experiment should be estimated by a level 0.2%. This accuracy is comparable with the accuracy of the polarization determination. However as was mentioned in Ref. [9], the accuracy of polarization can be improved to 0.1% in the case of using a supermirrors to prepare the beam polarization. Systematical error can be also decreased due to using of electron detector with high energy resolution.

The future prospects of this experiment which was mentioned before allow us to discuss improvement of this limit up to 500 GeV/c^2.

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