(ν, e) SCATTERING AND SEARCH FOR NEUTRINO MAGNETIC MOMENT

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Experimental problems associated with neutrino magnetic moment search at a level of $\approx 10^{-11}$ of the Bohr magneton are considered. New reactor ($\tilde{\nu}_e$, e)-elastic scattering experiment, prepared by Petersburg Nuclear Physics Institute and Kurchatov Institute, is described.

Introduction

A fundamental process of low energy electron-neutrino elastic scattering still presents a primary interest for the experimental study. An accuracy of the scattered electron spectrum measured in keV region defines a possibility to study some effects beyond the Standard Model such as energy dependence of $Sin^2\theta_W$ and a limit for neutrino magnetic moment in the range of $\mu_\nu \approx 10^{-11}$ of the Bohr magneton. The last one is the primary interest of this report.

The measurement of the ($\tilde{\nu}_e$, e)-scattering cross section with an accuracy of 30 – 50 % were performed by F. Reines at Savannah River reactor [1], V.P. Martemyanov at Krasnoyarsk reactor [2] and L. Popeko at Rovno reactor [3]. All of them are consistent with the Standard Model. The result achieved at Rovno reactor in the interval 0.6 – 2.0 MeV is $\sigma_{\tilde{\nu},e} = (1.26 \pm 0.62)\times 10^{-44}\,\mathrm{cm}^2\,/\,\mathrm{fission}$ and it gives the most stringent limit of the neutrino magnetic moment $\mu_\nu \leq 1.5\times 10^{-10}\,\mu_B$ at 68% C.L.

NESSI 1 - PNPI project

The experimental investigation of low energy Neutrino Electron Scattering, using Silicon detector, NESSI project, is performing in Petersburg Nuclear Physics Institute since eighties. A difficulty of this experiment consists in a trifle of the cross section (10^{-44}cm^2) and scattered electron is the only one detecting particle which does not have rather sharp flight direction. This experiment is ultra low background measurement of a radioactivity at the range of mBq/kg. We have found that the semiconducting silicon and germanium are sufficient for our purposes. The direct measurements of the radioactivity of non-enriched Si and Ge were performed in a deep underground laboratory. As a passive shielding we used semiconducting purity germanium [4]. An integral radioactivity of the *HPGe* detector with 50 keV threshold was 3 decay/h·kg and 90% of it was a result of the β^+ decay chain $^{68}Ge \to {}^{68}Ga$, produced by $^{70}Ge(n,3n)^{68}Ge$ cosmic rays irradiation, when the detector was at the earth surface. An intrinsic radioactivity of silicon is one tenth of germanium, but the correspondent spectrum was flabby and non interpretable. We did not find an expected chain $^{32}Si \to {}^{32}P \to {}^{32}S$, which is formed from atmosphere argon by means of the cosmic muon irradiation $^{40}Ar(\mu,2\alpha)^{32}Si$.

The ground of our project is the silicon multidetector of some hundreds kilogram of weight constructed of some thousands small silicon lithium drift detectors. To supply a large detector volume we produce coaxial two open ends lithium drift detectors.

We use sufficiently low price industry produced high resistive silicon 1000 – 2500 Ω·cm (Russian trade mark 2*Е*2–*Т*/*БКДБ*.27.5–30; *ТУ*48–4–295–82). It has the next dimensions: 27 – 30 mm in diameter, 100 – 150 mm of length, drift thickness is 12 mm, sensitive volume is up to 90%. Insensitive parts of a detector are: a diffusion lithium layer 0.3 mm thick, situated on a crystal surface; a central core which is non drift part of the original crystal.

The energy and efficiency calibration proceeds in the process of the detector production. The detectors with energy resolution better than 10 keV and with efficiency more than 85 % were considered as ready to use. Our experience of the detectors work and storage for more then 15 years shows a stability of the *Si*(*Li*) detector parameters within 3%.

The measurements of the $(\tilde{\nu}, e)$ scattering, using the silicon detectors 25 and 75 kg of weight were performed at Rovno electric power station in 1986 and 1993 [3]. The different multidetectors laying in the row runs have been used to minimize constructing materials inside the detector, to increase the reliability of contact systems and so on. The background in the last run was 400 counts/kg·d for 200 keV threshold. As the neutrino chamber at Rovno reactor situated on the earth surface, this background presumably has a cosmic ray activation nature. The only one way to improve the measurement condition consists in transferring the experiment to a deep underground reactor.

NESSI 2 – PNPI-KIAE project

A new run of the $(\widetilde{\nu}_e$,e)-measurement using the silicon detector now is in progress at Krasnoyarsk reactor, constructed within a mountain. It supplies some hundreds of m.w.e. from cosmic rays. An average muonic flux at the laboratory is about 1x 1/ m^2·s, that is, a factor of 1000 less than at Rovno reactor. The neutrino laboratory situated at distance of 18 m from the reactor core in the neutrino flux of $\Phi \cong 8\times10^{12}\,\widetilde{\nu}/\mathrm{cm}^2\mathrm{s}$. A new version of the 80 kg silicon detector is displayed on the Fig.1. It consists of four matrixes with 151 separate detectors in each matrix (Fig.2).

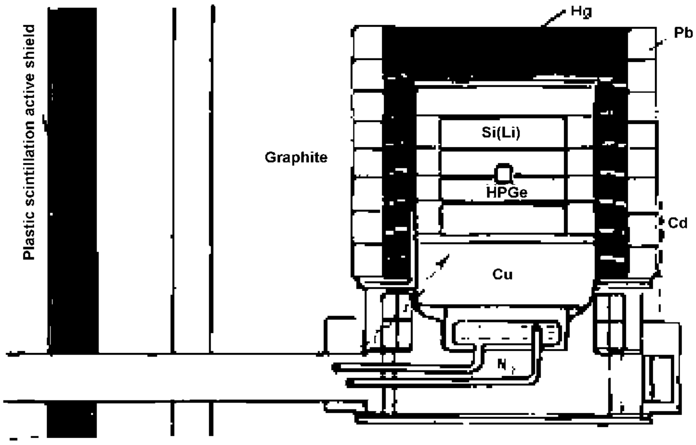
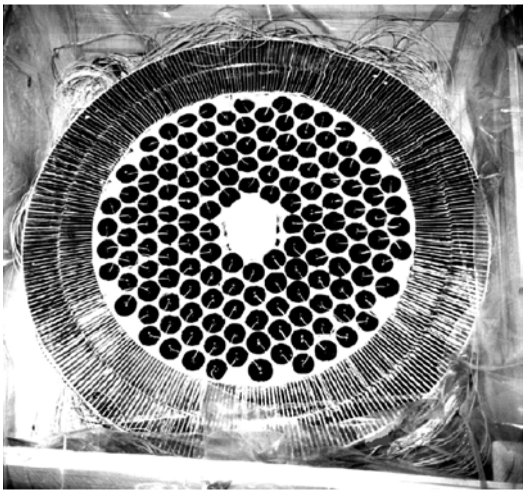


Fig. 1. Experimental set-up. The position of 4 silicon matrixes in the vacuum cryostat and heavy, graphite and active shielding are shown



The detector placed in a vacuum nitrogen cooled cryostat together with copper shield 90 mm thick. The total weight of cooled copper shielding, situated in vacuum, is 1600 kg. The shielding prevents the detector from radon irradiation and from radioactivity of the detector contact system. *HPGe* detector, 116 cm^3 in volume and 2 keV resolution is placed in the central cavern of the layout to measure a possible gamma ray background (Fig.3).

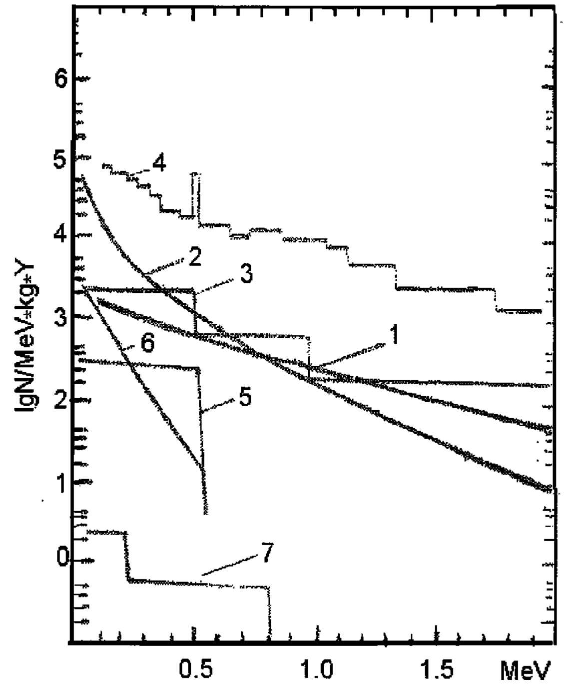


Fig. 3.
1 – the spectrum of scattered electrons due to $(\widetilde{\nu}_e, e)$ – weak interaction; 2 – the same due to magnetic moment for $\Phi_{\widetilde{\nu}} = 2.2\times10^{13}\,\widetilde{\nu}/\mathrm{cm}^2\cdot\mathrm{s}$; 3 – the background of 250 g Si(Li) detector in Ge shielding: deep underground measurement; 4 – the same for 620 g HPGe detector; 5, 6 – the same as 1 and 2 for $(\nu_e$,e) from chromium source Q=10^{17}1/s; 7 – weak scattering of solar neutrino

All the detectors switched on in anti-coinsidences together with the active shield. It consists of 120 plastic scintillation detectors, surrounding 15 m^3 volume of the silicon detector passive shielding. The electronic registration threshold is 50 keV. A trigger of the event is the work only of one of the detectors. Flash ADC digitized the sum signal from all the detectors in the 100 μs interval before and 100 μs one after of the triggered event. This information in the form of event file is writing in the computer memory. The criteria of the ($\tilde{\nu}_e$, e) events is the Gaussian shape of a single pulse from one of silicon modules within 200 μs time interval. Preliminary measurements performed in 1999 show the detector background is 1000 1/d for energy interval of 0.6 – 2.0 MeV, that is, one order better than in our Rovno experiment.

We expect an integral counting rate of the weak scattering will be 100 1/d. Krasnoyarsk reactor has a 40-day campaign. Consecutive measurements are separated by a short period of just 12 – 20 d. As a result, an expected sensitivity to the neutrino magnetic moment is $\mu_\nu \approx 3\cdot 10^{-11}$ of the Bohr magneton will be achieved for one year of the measurement.

NESSI 3

What is the prospect to reach the sensitivity $1\cdot 10^{-11}\mu_B$? This value is a limit for the possible explanation of solar neutrino deficit [5]. One of the problem solution is the measurement neutrino-electron scattering from a neutrino produced by a radioactive source [6].

The differential cross section due to weak interaction is:

$$\frac{d\sigma^W}{dT_e} = 1.07\times 10^{-45}\, cm^2/MeV\left[(1+2\ \mathrm{Sin}^2\theta_W)^2 + 4Sin^4\theta_W(1+\frac{T_e}{E_\nu})^2 - 2Sin^2\theta_W(1+2Sin^2\theta_W)\, m_e\cdot T_e/2E_\nu^2\right] \cong$$

$$\cong 2.3\cdot 10^{-45}\cdot(1+\alpha)\cdot f(E_e)\ \mathrm{cm^2/MeV}$$

The correspondent expression due to magnetic moment is:

$$\frac{d\sigma^M}{dT_e} = 2.5\times 10^{-45}\mu^2\left(\frac{1}{T_e}-\frac{1}{E_\nu}\right)\mathrm{cm}^2/\mathrm{MeV},$$

where T_e, E_ν are energies of scattered electron and neutrino in MeV, $\alpha << 1$, $f(T_e)$ is a smooth function of energy of scattered electron , μ is neutrino magnetic moment in 10^{-10} of the Bohr magneton.

The observed spectrum of weak scattered electrons for low energy monochromatic neutrino, such as 0.75 MeV neutrino from ^{51}Cr source, has very simple and interpretable shape as a step function. In opposite, magnetic scattering has a shape of fast falling function (see Fig.3.) To achieve the desired sensitivity we have to measure the scattered electron spectrum with a 50 KeV threshold.

The new high flux research reactor PIK in Gatchina has a central irradiating channel with a neutron flux of $5\cdot 10^{15}$ neutron/$cm^2\cdot$s. It has the special 400 kW cooling loop, independent of the first contour of the reactor. The calculation shows that we can get ^{51}Cr neutrino source $1\cdot 10^{17}$ν/s (some MCi) as a result of irradiating of 500 g of 92 % enrichment of ^{51}Cr for one 40 day campaign.

The detector is under construction. In principal, it is designed familiar to that described in this report for reactor experiment, but is enlarged in one order. Each section contents 814 detectors. The total mass of the detector is 1025 kg. The distance between source and detector is 820 mm. The neutrino flux on the central detector plane is $1.2 \cdot 10^{12}$ $\nu/cm^2 \cdot s$. An expected integral counting rate is 1280 for one run of 40 d. A possibility to measure “effect” and “background” with a period of some hours allows to achieve desired sensitivity during a year.

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