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Silicon detectors for low background and neutrino physics

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Abstract

The recent development of a large volume silicon semiconductor detector with high resolution is discussed. We present the results of the experiment on neutrino-electron scattering using a 80 kg silicon detector and reactor antineutrinos. A future project with improved sensitivity of a 1000 kg silicon detector and an artificial ⁵¹Cr neutrino source is briefly described.

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1. Introduction

The construction of a big volume and low background nuclear particle detector with an energy resolution of some keV is still a demanding task for modern instrumentation. Such a detector would be best for solar neutrino detection, neutrino detection from nuclear power reactors and other rear processes such as dark matter searches. The most appropriate materials for such a detector are Ge and Si. They are the purest solid state materials in modern technology. A high resistivity silicon (more than 1000 Ω cm) contains 10¹³ uncontrolled atoms per cm³, i.e. the purity is ~ 10⁻¹⁰.

The direct measurement of the intrinsic radioactivity of natural germanium and silicon have been done in our work [1], when we measured the background of HPGe and Si(Li) detectors in a thick semiconductor germanium shield in a deep underground laboratory (1000 m water equivalent). It is known that silicon taken from the earth surface contains long lived ³²Si(³²Si → ³²P → ³²S), which is formed from argon in the atmosphere by means of cosmic muon irradiation ⁴⁰Ar(μ, 2α)³²Si. Our measurements of the Si(Li) detector background shows, that an upper limit of the ³²Si content is 10⁻²⁰; that is 100 times lower than the one for surface samples. The reason of the difference is the special ore for semiconductor silicon production, which is taken from quartz sand, situated deep underground.

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2. The NESSI project (neutrino electron scattering with silicon detector)

The basis of our project is a ~ 1000 kg silicon multi detector made of thousands small Si(Li) detectors. An advantage of the silicon detector for the low background experiments is the low atomic number which is responsible for a suppression of the gamma ray background through Compton scattering. We use sufficiently low cost industrially produced high resistivity silicon (1000–2500 Ω cm).¹ To supply such a large number of modules we produce coaxial type lithium drift detectors.

The detectors have the following dimensions: 28–30 mm in diameter, 100 mm of length, the drift thickness is 12 mm; the sensitive volume is up to 90%. Insensitive parts of the detector are: a diffusion lithium layer 0.3 mm thick situated on the crystal surface and the central core. The lithium layer and the p-type core form n^- and p^+ of a diode, respectively. In our laboratory thousand silicon–lithium drift detectors are produced a year. The main steps of the production process are: lapping, etching and washing of the crystal; applying the lithium on a side surface of the crystal and lithium diffusion; lithium drift in an electric field at a temperature of 140 °C for 250 h for a thickness of 12 mm; clean etching and test measurements. The energy and efficiency calibration is done by the measurement of the electric capacity as a function of the voltage applied and the counting rate of a ^{60}Co and ^{137}Cs source with known activity. Detectors with an energy resolution better than 5 keV and an efficiency of more than 90% are considered as ready to use. Our experience is that detectors stored at room temperature for 15 years show a stability of the Si(Li) detector parameters within 3%. The calibration spectrum of one of the silicon detectors is shown in Fig. 1. For comparison a HPGe spectrum is also presented. It can be seen that the total counting rate defined mainly by Compton scattering coincides for both detectors. The peaks of total absorption differ more than one order of magnitude that is proportional to the fifth power

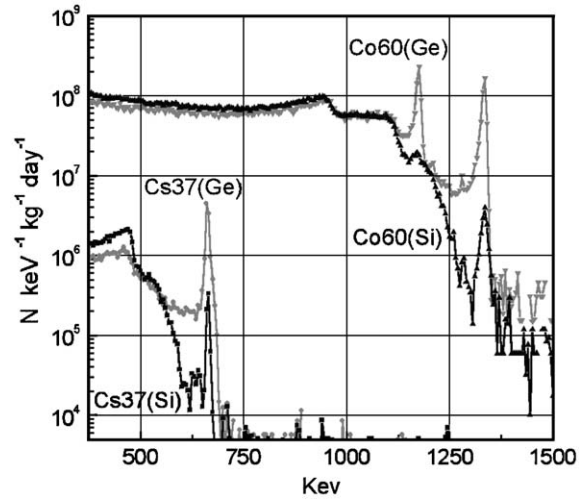


Fig. 1. Test measurement of a Si(Li) detectors (dark line). The same spectrum for a HPGe detector (gray line) is presented for comparison.

of the ratio of the atomic numbers. It confirms the advantage of the silicon multidetector over germanium for the suppression of the gamma-ray background at the sacrifice of the multiscattering process. The value of the gamma-ray background suppression depends on the size of the multi detector, the “dead” material inside and the lower energy registration threshold. Monte Carlo simulation of the gamma-ray absorption for a 1 m^3 detector with 10% “dead” material and 20 keV threshold gives a suppression coefficient of $K_s \sim 100$ for the background spectrum of natural radioactivity, which is defined by the ^{40}K , ^{238}U , ^{232}Th decay chains. For the model of the small detector discussed below, we measured $K_s = 6\text{--}10$ depending on the source position in respect to the detector (inner or outer, respectively). The Si(Li) detectors were installed in a matrix which consists of a Teflon holder and clean copper inner shielding, as it is seen in Fig. 2.

3. NESSI 1: reactor neutrino experiment

The fundamental process of low energy electron–neutrino elastic scattering still presents a primary interest for the experimental study. A precise

¹Russian trademark 2E2-1T/BKDB27-30; TU48-4-295-82.

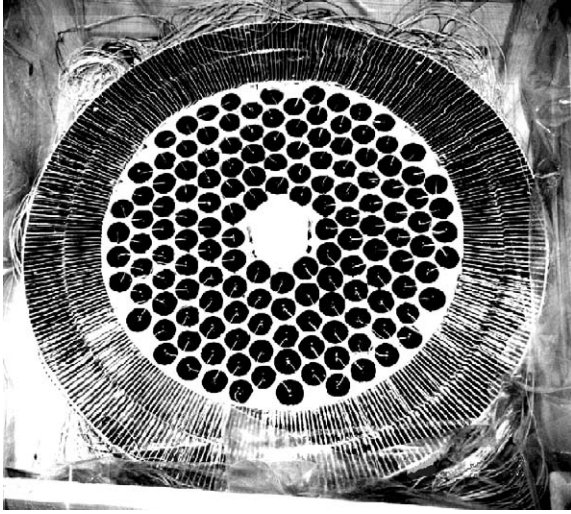


Fig. 2. Top view of a detector matrix.

measurement of the scattered electron spectrum in the keV region gives the possibility to study some effects beyond the Standard Model such as the energy dependence of $\sin^2\theta_w$ and a search for the neutrino magnetic moment in the range of $\mu_\nu \sim 10^{-11}$ of the Bohr magneton. The last one is the primary interest of this project.

The first experiment performed with a 37.5 kg silicon detector at the Rovno reactor, resulted in an upper limit of the neutrino magnetic moment of $\mu_\nu \leq 1.8 \times 10^{-10} \mu_B$ [2]. A new measurement of the $(\bar{\nu}_e, e)$ -scattering has started at the Krasnoyarsk reactor, which is situated inside a mountain. The low background neutrino laboratory in the Krasnoyarsk underground reactor is at a distance of 18.5 m from the reactor core. The neutrino flux on the detector is 0.8×10^{13} neutrino/cm²s. A new version of a 80 kg silicon detector with increased heavy shielding, situated in the vacuum chamber, is shown in Fig. 3. To control the background spectrum a detector with 116 cm³ volume and 2 keV resolutions is placed in the central cavern. The detector electronics is located in the area of the nitrogen-cooling bath. All detectors are switched on in anti-coincidences with the active shield. A trigger on a $(\bar{\nu}_e, e)$ -event is caused by only one of the detectors. The background of the 80 kg silicon detector in the heavy shield of 250 g/cm² is

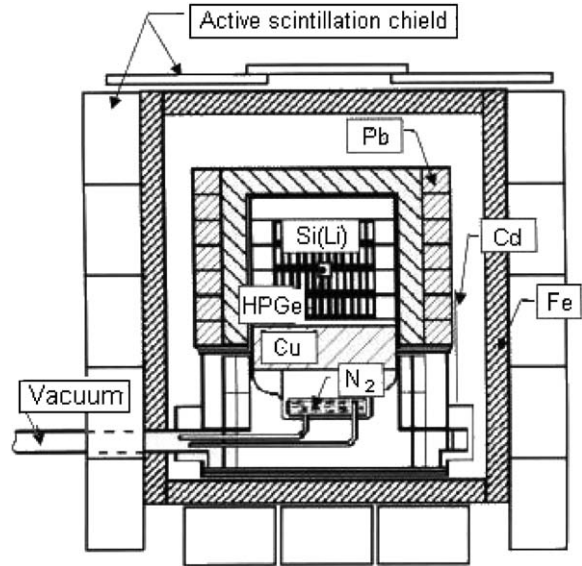


Fig. 3. The position of the silicon matrixes in a vacuum cryostat cooled by liquid nitrogen with passive and active shielding.

1200 c/day for the energy range 50–2000 keV. An estimated signal of $(\bar{\nu}_e, e)$ -scattering is 100 c/day. The measurement is in progress. We expect to reach a sensitivity for the neutrino magnetic moment of $\mu_\nu \simeq 3 \times 10^{-11} \mu_B$ in 1 year of measurements.

4. NESSI 2: neutrino–electron scattering with a Cr-51 source

We are proposing a measurement of (ν, e) -scattering from a neutrino produced by a radioactive source to reach a sensitivity of $10^{-11} \mu_B$ which is the limit for the possible explanation of the solar neutrino deficit [3].

The observed spectrum of weakly scattered electrons for low energy monochromatic neutrinos, such as a 0.75 MeV neutrinos from ⁵¹Cr, has a very simple shape of a step function. Magnetic scattering has a shape of a fast falling function. 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 that is under construction in Gatchina (Russia)

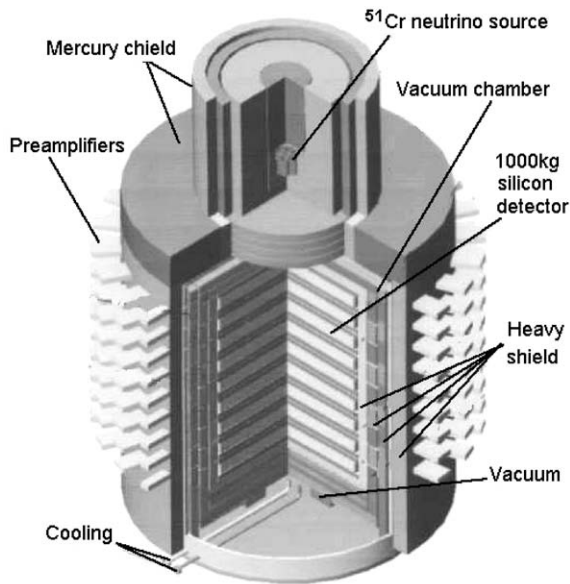


Fig. 4. Schematic overview of the NESSI 2 experiment.

has a central irradiating channel with a neutron flux of $\Phi_n = 5 \times 10^{15} \text{neutron cm}^{-2} \text{s}^{-1}$. We estimate that a ^{51}Cr neutrino source of $Q \sim 3 \times$

10^{17}v/s (some MCi) can be produced as a result of the irradiation of 500 g Cr (92% ^{50}Cr enriched) during 40 days reactor operation. The detector with $\sim 1000 \text{kg}$ of mass is under construction (see Fig. 4). In principal, it is designed similar to that described in this report for the reactor experiment, but is enlarged in order to increase the suppression coefficient up to the calculated one for a large detector, i.e. $K_s \sim 100$. It will consist of 9 matrixes. Each one will contain 814 Si(Li) detectors. The distance between the source and the detector is 820 mm. The expected integral counting rate is 1280 for one run of 40 day. The possibility to measure “signal” and “background” with a period of some hours allows to achieve the desired sensitivity during a year.

References

- [1] L. Popeko, A. Derbin, A. Cherny, G. Shishkina, Sov. JETPH Lett. 50 (1989) 222.
- [2] L. Popeko, et al., Sov. JETPH Lett. 57 (1993) 755.
- [3] M. Woloshin, L. Okun, Sov. Nucl. Phys. 48 (1988) 967; M. Woloshin, L. Okun, Sov. Nucl. Phys. 49 (1989) 564.