Investigation of neutrino properties with the low-background germanium spectrometer GEMMA-III

JINR group: V.V.Belov, V.B.Brudanin, V.G.Egorov, M.V.Fomina, A.V.Lubashevskiy, D.V.Medvedev, D.V.Ponomarev, V.G.Sandukovsky, M.V.Shirchenko, S.V.Rozov, I.E.Rozova, I.V.Zhitnikov, E.A.Yakushev, D.R.Zinatulina.

The GEMMA-III project is aimed to investigate fundamental properties of neutrino at close vicinity of the reactor core of Kalinin Nuclear Power Plant (KNPP). The GEMMA collaboration consists of scientists from JINR (Dubna), ITEP (Moscow) and MEPhI (Moscow).

Measurement of the neutrino properties is a very important task for particle physics, astrophysics and cosmology. Being one of the most abundant particle in the Universe its detection is very challenging due to a very weak interaction with matter. To investigate its properties, it is required to have a very strong source of the neutrinos and apply various methods for the suppression of background events. A magnetic moment is the fundamental parameter of the neutrino and its investigation may lead to results beyond the standard concepts of elementary particle physics and astrophysics. The Minimally Extended Standard Model predicts a very small magnetic moment value for the massive neutrino ($\mu_\nu < 10^{-19}\mu_B$) that cannot be observed in a present experiment. However, there are a number of theory extensions beyond the Standard Model where Magnetic Moment of Neutrino (MMN) could be at the level of $10^{-(10\div12)}$ μ_B for Majorana neutrino. The observation of MMN value higher than 10^{-14} μ_B would be an evidence of New Physics and would give an evidence that neutrino is a Majorana particle. Coherent Elastic Neutrino-Nucleus Scattering (CENNS) is a process predicted by the Standard Model, but has not been observed yet for the reactor neutrino. The detection of this process would be an important test of the Standard Model. Such observations can also help for search for non-standard neutrino interactions, sterile neutrinos and other investigations. Due to a low cross section and a tiny energy deposition, it is not easy to observe such a process.

The GEMMA-III is a new experiment under construction at the Kalinin Nuclear Power Plant for detection of these processes. This experiment is an evolution of our previous projects GEMMA and νGEN. The first phase of the project (GEMMA-I) set up the world best upper limit for MMN of $< 2.9\cdot10^{-11}\mu_B$ (90% CL). The measurements were performed with 1.5 kg High Purity germanium detector which has the effective energy threshold of about 2.8 keV. Using passive and active methods of the background suppression in GEMMA-I experiment it was possible to achieve background level at the low energy region of about 2.5 cts/(keV·kg·day)$^{-1}$.

The GEMMA-III project will move the investigations of the neutrino properties on a new level of sensitivity. The experimental setup is located at about 10 m from the 3 GW_{th} reactor core of KNPP. This allows to operate a neutrino flux greater than $5\cdot10^{13}$ per cm^2 per second. The available place for the measurement is located just under the reactor, which provides about 50 m w.e. shielding from cosmic rays. The scheme of the reactor is shown in Fig.1, left.

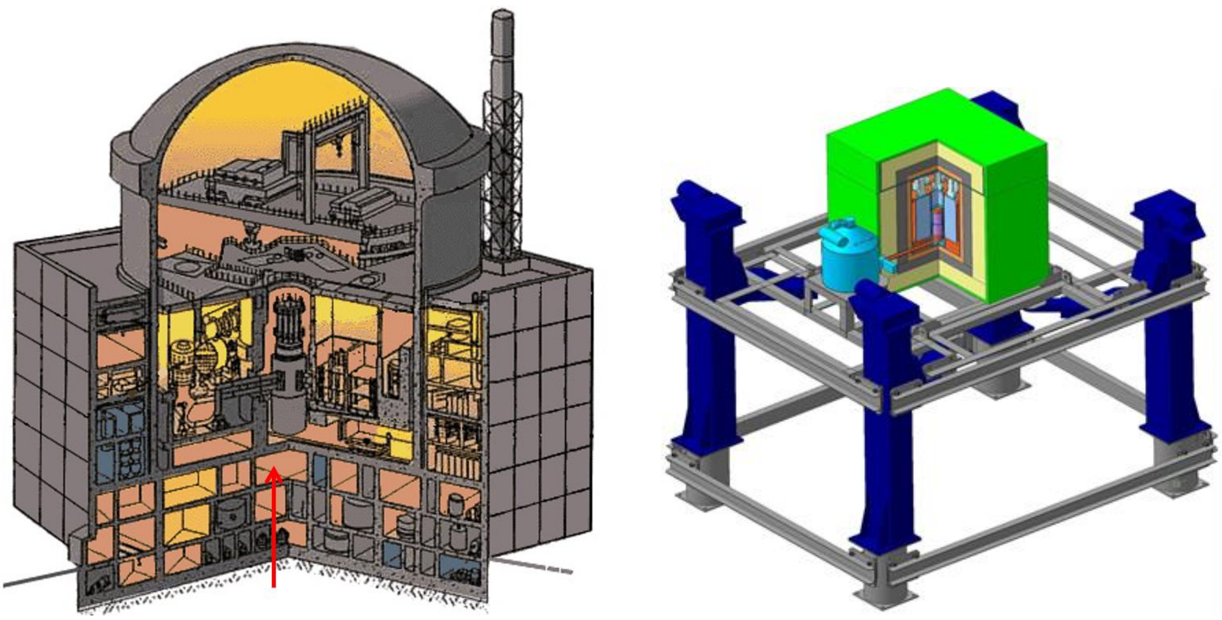

Figure 1. Left: the scheme of the reactor unit #3 at KNPP. Arrow indicates the room where experimental setup is being constructed. Right: the scheme of the spectrometer placed on the lifting mechanism.

A special lifting mechanism allows to move the spectrometer away from the reactor core, suppressing main systematic errors caused by possible long-term instability and neutrino flux (Fig.1, right). It gives us an opportunity to vary on-line the antineutrino flux significantly and reduce uncertainties of the background.

Currently investigations were performed within vGEN project. Four low background HPGe detectors with modified p+ contact produced in cooperation between JINR (Dubna) and BSI (Riga) are used to detect CENNS. The total mass of the detectors is about 1.6 kg. The detectors are placed inside a low background U-type cryostat (see Fig. 2).

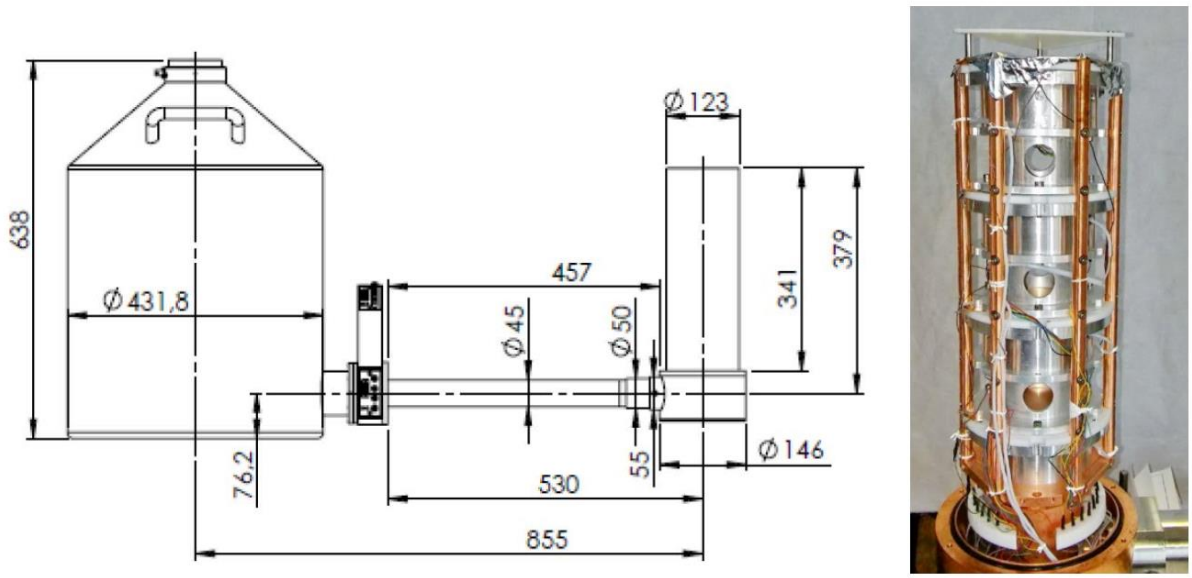

Figure 2. Left: general scheme of the vGeN cryostat for 4 HPGe detectors. Right: photo of the internal part that includes holders for 4 HPGe detectors.

The vGeN HPGe detectors were tested at the LSM underground laboratory in a low-background passive shield made from copper and lead. For the energy region from 100 to 600 keV the background index was found to be 0.66±0.03 cpd/(kg·keV). Fig. 3 demonstrates the experimental low energy spectrum for one of the detectors.

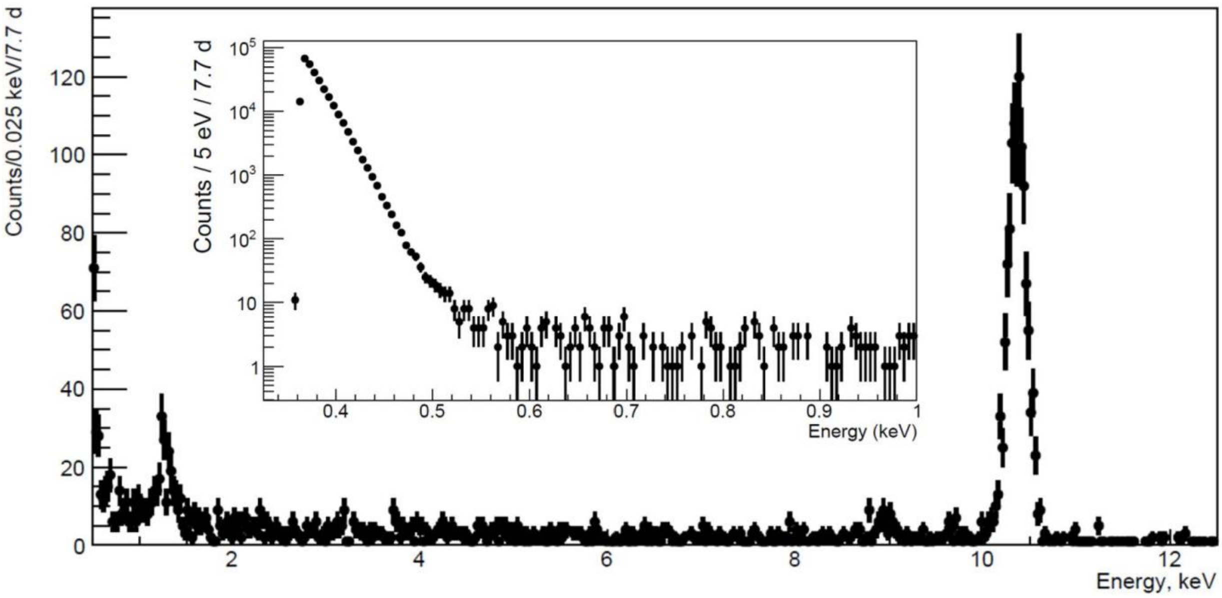

Figure 3. The low energy spectrum for detector N4. The energy scale was calibrated with clearly detected 1.3 keV and 10.37 keV cosmogenic lines. The low energy part of the spectrum is shown as the insert with the logarithmic scale.

Simplified acquisition system was used during the tests. The main conclusion of the performed tests is that achieved energy thresholds and preliminary values of the experimental background are adequate in order to start further commissioning of the setup with proper acquisition chain and the veto systems at the KNPP experimental site.

After radiopurity tests at LSM, detectors were moved to JINR (Dubna). A new acquisition system has been installed. Signal from germanium detector currently are taken by means of real time ADC. The best energy resolution achieved with a pulse generator is about 170 eV (FWHM). The noise events are being suppressed by comparing signals reconstructed with different shaping times of amplifiers. Periodical noise is suppressed by the time cut. Calibration with a pulse generator demonstrates that after applying all cuts it is still possible to detect events with energy below 350 eV with an efficiency of about 70%. This should be sufficient for detection of CENNS. After these tests the spectrometer was moved to the experimental room at KNPP. Currently we are constructing a passive shielding around of νGEN spectrometer. The data taking for the CENNS is going to start this year.

At the same time, we are planning to increase the sensitivity of the experiment by using detectors with a higher masses and lower threshold. Such an upgrade is called GEMMA-III project. Recent development on a detector production allows us to produce detectors with significantly higher resolution than it was achieved before. New detectors produced by CANBERRA have resolution below 80 eV (FWHM) with masses of a few kg. It is possible to work with an energy threshold below 200 eV with them. This energy threshold increase greatly the number of events from neutrino scattering and increase sensitivity of the experimental setup.

Using all infrastructure developed for νGEN experiment we are going to swap existing νGEN cryostat by a newly produced CANBERRA detectors. The first 1 kg detector after successful testing at LSM will arrive to JINR in the beginning of 2018. After its arrival we are planning to move it to KNPP and replace νGEN spectrometer. Altogether, we are planning to use four detectors with a total detector mass of about 5.5 kg. The detectors should be ready in the end of 2018. This allows to detect of about 190 events from CENNS per day. The sensitivity to magnetic moment of the neutrino would be about $9 \cdot 10^{-12}$ μ_B after several years of data taking.

Thus, the project GEMMA-III is the continuation of predecessor projects GEMMA and vGEN. By previous steps it was demonstrated that our group is able to perform modern investigations with HPGe detectors achieving very low background level on a shallow depth. The limit on a magnetic moment of the neutrino obtained in the GEMMA-I experiment is the best in the world so far beyond the terrestrial experiments. We are going to continue our studies and improve our knowledge on the neutrino parameters.