Annex 3.

Form of opening (renewal) for Project

APPROVED

JINR DIRECTOR

_____________/___________________

"_____" ______________________ **2023 г.**

PROJECT PROPOSAL FORM

Opening/renewal of a research project/subproject of the large research infrastructure project within the Topical plan of JINR

1. General information on the research project of the theme

1.1 Theme code / LRIP (for extended projects)
03-2-1100-2010/2024

1.2 Project/LRIP subproject code (for extended projects)

1.3 Laboratory
Dzhelepov Laboratory of Nuclear Problem

1.4 Scientific field
Nuclear physics

1.5 Title of the project/LRIP subproject
Nuclear spectrometry for the search and investigation of rare phenomena

1.6 Project/LRIP subproject leader(s)
D. Zinatulina

1.7 Project/LRIP subproject deputy leader(s) (scientific supervisor(s))
K. Gusev, N. Rukhadze, O. Kochetov, S. Rozov

2 Scientific case and project organization

2.1 Annotation

The project "Nuclear spectrometry for the search and study of rare phenomena" consists of five main experiments: LEGEND (The **L**arge **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless double beta **D**ecay), TGV (**T**elescope **G**ermanium **V**ertical), SuperNEMO (**N**eutrino **E**ttore **M**ajorana **O**bservatory), MONUMENT (**M**uon **O**rdinary capture for the **NU**clear **M**atrix elem**ENT**s) и EDELWEISS (**E**xpérience pour **DE**tecter **L**es **W**IMPs **E**n **S**ite **S**outerrain).. The first four experiments solve the problems of search and studying neutrinoless double beta decay. The EDELWEISS experiment aims to search for dark matter particles.

Search for the neutrinoless double beta decay (0nbb) is one of the priority tasks of the modern physics. Its discovery would play a fundamental role not only for neutrino physics itself, but also for particle physics and cosmology. It would also allow determining the nature of the neutrino (Majorana or Dirac), testing the hierarchy of neutrino masses and possibly finding the effects occurring because of the violation of CP invariance. The discovery of 0nbb decay could shed light on the reason for the prevalence of matter over antimatter in our Universe.

The **L**arge **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless double beta **D**ecay (**LEGEND**) experiment (the successor of the GERDA experiment) is designed to search for neutrinoless double beta (0νββ) decay of ^{76}Ge. In the experiment germanium detectors fabricated from isotopically enriched material will be operated inside a cryogenic fluid shield. The experiment will probe the 0νββ decay of ^{76}Ge with a sensitivity of $> 10^{28}$ years at 90% confidence level (C.L.).

The 200-kg phase (LEGEND-200), currently starting data taking in the modified GERDA infrastructure at LNGS, is using the enriched detectors from the previous Majorana and GERDA experiments as well as new detectors for a total mass of up to 200 kg. The background projection of the LEGEND-200 is a factor of 5 below the measured levels of GERDA, reaching a level of $< 10^{-4}$ counts/(keV kg yr). A scaling toward a 1000-kg phase incorporating a further factor of 10 reduction in background beyond LEGEND-200 at a level of $< 10^{-5}$ counts/(keV kg yr) will provide discovery potential that encompasses the inverted hierarchy mass region for the light left-handed Majorana neutrino exchange mechanism. LEGEND-1000 will probe a large/relevant part of the parameter space even if the ordering is normal.

Following activity is based on the investigation of ECEC process using a low-background multi-detector Ge spectrometer **TGV** (Telescope Germanium Vertical) and passive double beta emitters made from enriched isotopes. The high-sensitivity spectrometer TGV was developed in JINR for investigations of double beta decay with small amount of rare, enriched isotopes and was mounted in the deep underground laboratory. Small distance from external (passive) double beta emitters to HPGe detectors allows us to obtain high detection efficiency for various types of useful single and coincidence **(β-β, β-γ, γ-γ, X-γ, X-X)** events resulting in strong suppression of the external background. This advantage of TGV is especially important for detection of double coincidences of low energy KX-KX events accompanying of ECEC decays. This stage of the experiment is aimed for the improving energy resolution of TGV detectors, suppressing their background, modification of the electronic part of the spectrometer and its acquisition. After these updates spectrometer TGV will be used for further investigations of ECEC decay of ^{106}Cd and ^{130}Ba. According of our estimation and theoretical prediction for these rare processes we hope to detect both decays in direct experiment for the first time. It should be also mentioned that interest in studying the double-beta decay to excited states of daughter nuclei has grown recently, due to the search for the resonant neutrino-less double electron capture (0νEC/EC) within some nuclei and the investigation of two-neutrino double beta decay processes ($2\nu 2\beta^-$, $2\nu\beta^+$EC, 2νEC/EC) to excited states of daughter nuclei. The smaller transition energies leads to the substantially suppressed probabilities for 2νββ - decay to excited states in comparison with 2νββ transitions to the ground state. But such processes are accompanied by emission of γ -quanta in the de-excitation of excited states, and 2νββ -decay to the excited states of the daughter nuclei may be detected for some nuclei (e.g. ^{100}Mo, ^{82}Se, ^{96}Zr, ^{150}Nd) using highly efficient low-background HPGe detectors, for example, the **Obelix** and **Idefix** detectors. The search for 2νββ decay using the Obelix and Idefix detectors is another additional activity in this project.

The main advantage of the **SuperNEMO** project is a unique potentially zero background tracking-calorimetric technique, which allows identification of e^-, e^+, a and γ particles, the reconstruction of the event topology and of the full kinematics of detected particles, including individual energies and emission angles. This allows testing different 0νββ-decay mechanisms in the case of discovery. The SuperNEMO Demonstrator Module was recently commissioned in the Laboratoire Souterrain de Modane in the 4,800 m.w.e. deep Fréjus tunnel in France. The physics program of the SuperNEMO Demonstrator Module consists of precision measurements of the 2νββ decay mode to constrain nuclear and BSM physics, as well as the best limits on 0νββ, for the isotope ^{82}Se.

The purpose of the **MONUMENT** project is carrying out experimental measurements of muon capture at several daughter candidates for 0nbb decay nuclei. Obtained results would be drastically important for checking the accuracy of theoretical calculations of NME. This project continues and extends the previous OMC measurement program proposed and implemented under the guidance of JINR employees from 1998 to 2006. Throughout the period from 2020 to 2023 the OMC measurements for ^{136}Ba isotopes, ^{76}Se and ^{100}Mo have been done. The OMC on ^{136}Ba and ^{76}Se is of particular importance for the planned leading experimental searches for the 0νββ decay of ^{136}Xe – nEXO, KamLAND2-Zen, NEXT, DARWIN, and PandaX-III – and of ^{76}Ge – LEGEND. We propose to extend the project with the measurement program for another three years and carry out measurements of enriched ^{48}Ti, ^{32}S, ^{56}Fe and ^{96}Mo isotopes, these results are important for the experimental verification of theoretical calculations and may be useful for astrophysics. The JINR will play a leading role in the experiment. With the exception of the experimental infrastructure at the accelerator complex, which will be provided by our collaborators, the rest of the project will be carried out under our supervision.

In direct searches for Dark Matter (DM) a technology developing by **EDELWEISS** experiment is arrays of Ge mono-crystal detectors operated at a temperature of few mK and equipped with electrodes and thermal sensors. Applying a small (few V/cm) external field, a simultaneous measurement of ionization and heat signals allows efficient identification of nuclear and electron recoils. New results demonstrated the high relevance of cryogenic Ge detectors for the search of DM interactions producing eV-scale signals. The region of "light WIMPs" will be further investigated in the EDELWEISS experiment thanks to advantage of energy resolution below 20 eV reachable with new array of HPGe bolometers. This stage is in the R&D phase, building of improved detectors, their holders and supports, improvement of the background and acquisition. The unlimited target of current R&D and measurements in the EDELWEISS experiment is achievement of sensitivity allowing detection of B-8 solar neutrinos through coherent elastic neutrino-nucleus scattering (CEvNS). The project is the transformation phase, when the old setup used from 2005 start to be decommissioned with the aim to have smaller low level background setup with new generation of the cryosystem that allowed timely execution of intensive r&d program. For few next years the EDELWEISS detectors will be hosted by BINGO setup (development of the CUPID-Mo programm, that has been hosted by the EDELWEISS).

2.2 Scientific case (aim, relevance and scientific novelty, methods and approaches, techniques, expected results, risks)

The evidence for neutrino flavor oscillations has convincingly shown that neutrino has a finite mass. However, the fundamental question whether neutrino is Majorana (particle is equal to its own antiparticle) or Dirac particle is still unanswered. The only known practical way to probe the Majorana nature of neutrinos experimentally is via the discovery of the 0νββ decay. Moreover, this process violates lepton number conservation. Hence, it is forbidden within the Standard Model (SM) of particle physics. Therefore, the discovery of 0νββ decay will confirm the existence of New Physics beyond SM. The half-life sensitivity of 0νββ experiments grows linearly with the exposure (kg yr) as long as there are no background counts in the region of interest (ROI) close to decay energy. GERDA Phase II was the first background free search for 0νββ decay because of achieved unique background level of 10^{-3} counts/(keV kg yr). It allowed GERDA to reach planned sensitivity of $> 10^{26}$ years. Building on the experience with the background reduction technique, the next generation project **LEGEND** is being advanced. The experiment is foreseen to proceed in at least two phases. The first phase (LEGEND-200) plans to operate up to 200 kg of enriched Ge and to reach the sensitivity of 10^{27} years, the second phase (LEGEND-1000) – up to 1000 kg and 10^{28} years respectively. The aim of the new project is to answer the question about neutrino mass hierarchy. It is also very essential, that ultra-low background germanium-based experiments have better 0νββ discovery potential compared with all competitors thanks to the excellent energy resolution of Ge detectors.

Methods and approaches, methodologies

The LEGEND project as well as the predecessor GERDA experiment searching for neutrinoless double beta decay of ^{76}Ge. These experiments employ semiconductor diodes made from Ge enriched in ^{76}Ge so a detector acts also as a source. The detectors are directly immersed in liquid argon that works as a cooling medium and simultaneously as an additional passive and active shield against external radioactivity.

The experimental signature for discovery of 0νββ decay is a peak in the electron sum spectrum at the decay energy of the isotope under consideration. This makes the energy resolution very essential and gives the advantage to the experiments exploited Ge detectors.

A main feature of **LEGEND-200** is the reuse of the existing GERDA infrastructure located at the Laboratori Nazionali del Gran Sasso (LNGS) of INFN in Italy. It is placed underground below a rock overburden of about 3500m water equivalent that reduces the muon flux to ~1.25/(m^2 h). On Fig. 1 left shows a cross section through the current installation. LEGEND-200 as well as GERDA is using germanium detectors arranged in strings (covered by nylon mini-shrouds to reduce the background from ^{42}Ar) inside a cryostat filled with 64 m^3 of liquid argon. The cryostat is located inside a water tank of 10 m in diameter. The 590 m^3 of high purity water moderate ambient neutrons and γ radiation. It is instrumented with 66 PMTs and operates as a Cherenkov muon veto to reduce further cosmic induced backgrounds to insignificant levels for the LEGEND experiment. A glove box and the lock for integration and deployment of the Ge detectors is placed in a clean room on top of the cryostat and water tank.

The readout electronics for LEGEND-200 is a system that comprises improved Majorana LMFE and GERDA charge-sensitive preamplifier with new interconnects that can be deployed by the lock.

LEGEND-200 LAr veto system builds on the successful liquid argon instrumentation pioneered by the GERDA collaboration and adopts wavelength shifting (WLS) fibers which are reading out with SiPMs as developed and tested in GERDA. Improved geometrical fiber coverage increases the photo electron yield together with an improved liquid argon quality of a factor of two or more while keeping the trigger threshold to discard a background event at the single photo electron level. Given the increased number of detector strings in LEGEND-200 with respect to GERDA, the scintillation light emitted inside the Ge detector array has a reduced likelihood to reach an outer WLS-fiber element. For this reason, also the internal WLS-fiber shroud has been deployed. The final design of LEGEND-200 LAr veto (Fig. 1 right) has been developed by JINR and TUM specialists.

The background due to ^{42}Ar stays essential for LEGEND-200, so as well as in GERDA we had to create a mechanical barrier, called ‘mini-shroud’ (MS), enclosed the space around the detector string, which prevents the collection of ^{42}K ions on the detector surfaces. This barrier should be transparent otherwise the LAr veto system couldn’t register the scintillation light from the area close to the detectors. For LEGEND-200 the JINR team stays responsible for the R&D and production of all nylon MSs.

Tooling in the glovebox for LEGEND was designed, provided and installed by JINR team. It is based on the GERDA design but some serious modifications to deal with longer strings were needed. However, the main idea of LEGEND string mounting system significantly differs from GERDA and allows to mount the detectors in strings close to the lock in order to avoid moving of assembled string along the glove box. Using this system 101 Ge detectors have been already installed in the setup.

LEGEND-1000 is on CDR stage now. The location of the experiment is still under consideration (SNOLAB, Canada or LNGS, Italy). However, in both cases the baseline design is the same and includes the following main differences compared with LEGEND-200:

- Using underground Ar depleted in ^{42}Ar – no nylon MSs needed.
- Exploiting big inverted coaxial detectors only – average detector mass more than 2 kg.
- Using ASICs as the readout electronics.
- Switch to single string lock approach – every string will have its own LAr instrumentation and will be deployed through individual lock.

JINR team is expected to contribute to the project in the following: 1) Design and production of the ultra-low background detector holders; 2) Design and production of LAr instrumentation; 3) Design and procurement of the glove box with the string movement system; 4) Data taking (including on-site shifts); 5) Simulations and data analysis; 6) Publication of the results.

Expected results

The sensitivity to a 0νββ decay signal as a function of exposure and background is shown in Fig. 2, separately for a 3σ discovery and a 90% C.L. upper limit analysis. If an experiment's background is zero both the discovery sensitivity as well as the limit sensitivity scale linearly with the exposure, while in the background-dominated regime both sensitivities scale with the square root.

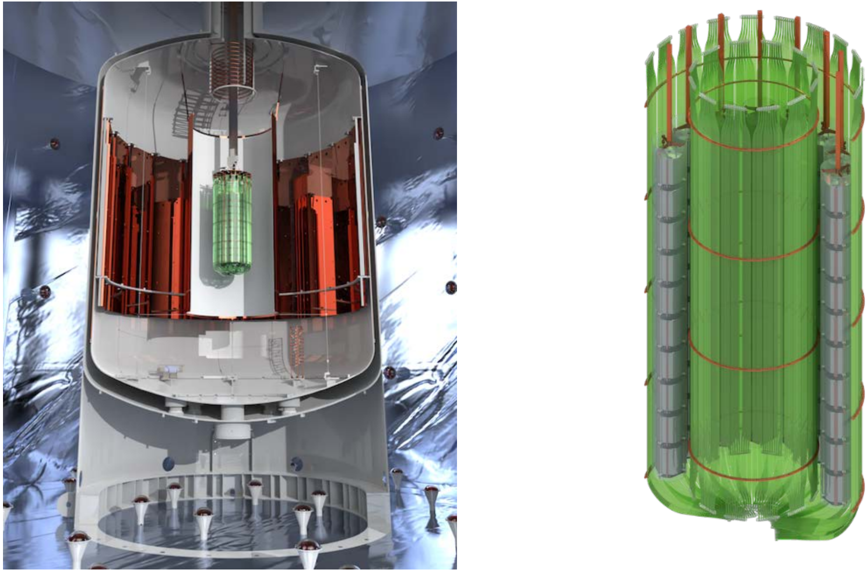

Fig. 1: *Cross section of the LEGEND-200 experiment (left) and final design of LAr instrumentation (right).*

For signal discovery a low background is especially important because as the expected number of background counts increases, the signal level required to obtain a 3σ excess grows rapidly. Even assuming a conservative background of 0.2 cts/(keV t yr) or 0.6 cts/(FWHM t yr), LEGEND-200 would reach a 3σ discovery sensitivity of > 10^{27} yr for an exposure of 1 t yr. The background in LEGEND-1000 is expected to be better which will allow to achieve the sensitivity of > 10^{28} yr after 10 years of data taking with 1 t of enriched Ge detectors.

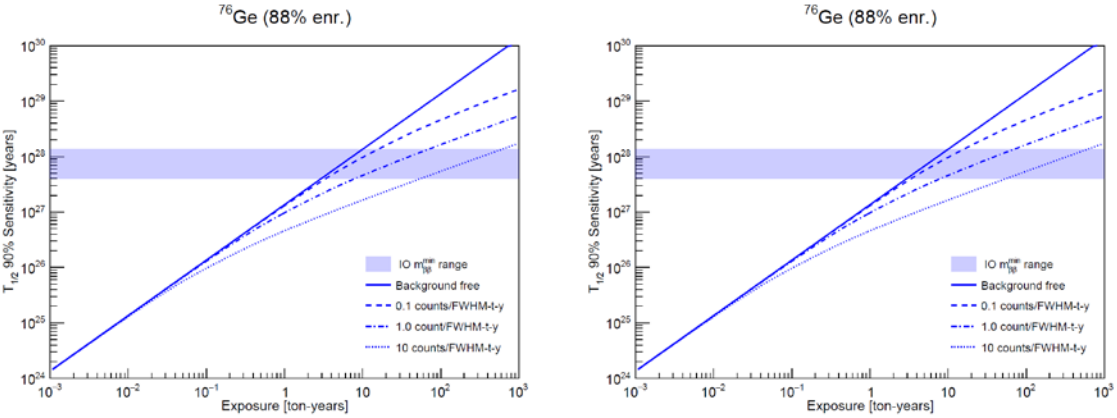

Fig. 2: *Sensitivity for setting a limit (left) or a signal discovery (right).*

Risks

The risk of not getting the expected sensitivity of **LEGEND-200** within 5 years of data taking is low since the experiment is running. The only hardware activity planned in 2024 is adding of additional detectors to reach the desired mass of 200 kg (now 140 kg). This will require full disassembling of LAr instrumentation and detector strings followed by reassembly of the setup with all detectors made from ^{76}Ge. All operations will be performed with the direct participation of JINR specialists and expected to be done by the same team. It significantly reduces the risk of unsuccess of this hardware activity as well as of LEGEND-200.

LEGEND-1000 will be build based on the experience gained from LEGEND-200. The start of LEGEND-1000 data taking can be delayed mainly due to the detector production rate lower than expected or to the high failure rate of produced detectors. Both will not allow to have total needed enriched germanium mass. However, this risk is low thanks to well-established detector technology.

Moreover, the fabrication capability of two existing companies has been checked already – many of newly produced detectors are being used in LEGEND-200 and performing well.

Another risk connected to the ASICs development that can advance slower than scheduled. To avoid this risk the LEGEND collaboration now has 3 groups working on this development in parallel.

The last but not least problem is the possibility to not reach the desired background level, but very careful assay of materials as well as the unique background level achieved by GERDA, significantly reduce this risk.

The main goal of the **TGV** experiment is the direct search for 2νECEC decay in ^{106}Cd and ^{130}Ba. Experiment started in 2005 with ~10g of ^{106}Cd with enrichment of 75%, and with the main participation of JINR scientists. In the third run of the experiment, which is now in progress, the mass of double beta emitters was highly increased up ~ 23.2 g of ^{106}Cd with enrichment of 99.57%.

Up to now more attention in investigation of double beta decay has been given to $\beta^-\beta^-$-decay, but there are other channels of double beta decay, in particular the double capture of two bound atomic electrons (EC/EC), capture of the bound electron with emission of a positron (β^+/EC) and decay with emission of two positrons ($\beta^+\beta^+$). Recently, interest in these processes has significantly increased, especially for ECEC decay. In contrast to the $2\nu\beta^-\beta^-$-decay with emitting of two electrons, which may be detected by various type of detectors, other double beta decay processes are difficult to observe in direct investigations due to experimental difficulties. For example, 2νECEC decay processes with transition to the ground state of daughter nuclei are accompanied only by low energy two characteristic X-rays, which are difficult to detect with high efficiency. High efficiency multi-detector spectrometer TGV based on HPGe detectors was developed specially to perform the direct search for 2νECEC decay processes. 2νECEC decay of ^{106}Cd was not obtained experimentally till now. The positive 2νECEC signal was obtained for ^{130}Ba using a geochemical technique. However, the robustness of this implicit experimental method is debatable and this result has to be confirmed by direct measurements, like TGV experiment.

Methods and approaches, methodologies

In the current activity spectrometer TGV will be focused to the direct search for two-neutrino EC/EC decay of ^{106}Cd and ^{130}Ba with transitions to the ground states of daughter nuclei. The real direct observation of these rare processes is possible only by detection of double coincidences of KX-KX low energy events accompanied of such decays. Detector part of TGV consists of 32 planar type HPGe detectors with the sensitive volume of 2040 mm^2 x 6 mm each (about 3 kg of Ge) and total sensitive volume of about 400 cm^3 (Fig.3). The energy resolution of the detectors ranged from 3.0 to 4.0 keV at the 1332 keV ^{60}Co γ-line. The total efficiency of the TGV-2 spectrometer is 50-70% depending on the energy threshold. The basic detection cell of TGV is a sandwich-like pair of face-to-face detectors with thin foils of double beta emitters placed between them. The distance between investigated samples and detectors is ≤1.5 mm. The 16 pairs of detectors are mounted one over another in a common cryostat tower. The detector design delivers high detection efficiency for various types of useful single and coincidence **(β-β, β-γ, γ-γ, X-γ, X-X)** events resulting in strong suppression of the external background. The detector part of the TGV is surrounded by: i) a copper shielding with a thickness of ≥20 cm; ii) a steel airtight box protecting from radon accumulation near the detectors; iii) a lead shielding with a thickness of ≥10 cm; iv) a neutron shielding made of borated polyethylene with a thickness of 16 cm. The spectrometer is located in the deep underground laboratory (4800 m w.e.) which allows us to suppress cosmic rays (reduction factor of $\sim 2\times10^6$) and fast neutrons (reduction factor of $\sim 10^3$). Further suppression of background was achieved by using coincidence techniques and filtering the electronic and microphone noise in the low energy region (<50 keV) by digitizing the detector response with different shaping times (2 and 8 μs). To realize this activity we already have TGV spectrometer (detectors, electronics, software), and 16 double beta emitters made from ^{106}Cd (enrichment 99.57%) with a total mass of ~ 23.2 g, installed inside detector part of TGV spectrometer between the entrance windows of detectors. All future activity in the TGV experiment: 1) update of the spectrometer, 2) data taking; 3) calculations; 4) publications of results; will be carried out mainly by JINR scientists.

Expected results

In the frame of this activity, we hope to detect 2νECEC decay of ^{106}Cd and 2νECEC decay of ^{130}Ba in the direct experiment.

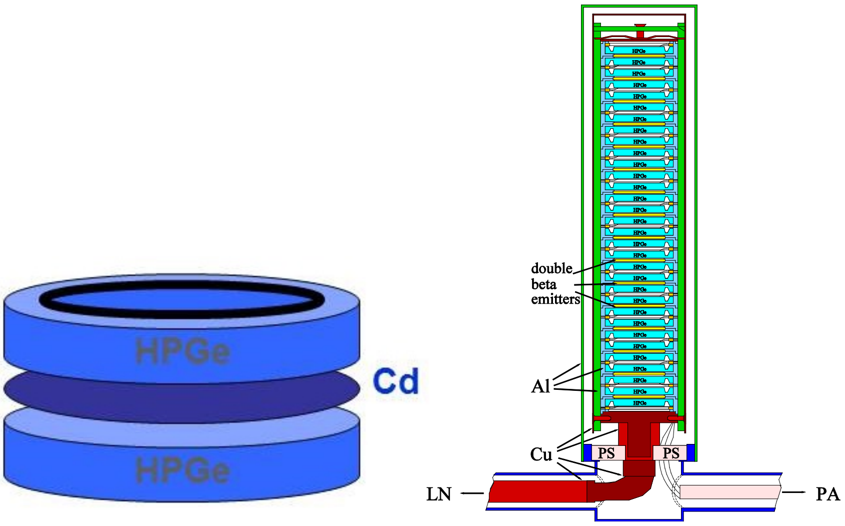

Fig. 3: *The detector part of low background spectrometer TGV with double beta emitters. On the left part of the picture there is a pair of detectors with a foil of* ^{106}*Cd*

Risks

Planning update of the TGV spectrometer may not give a significant improvement of energy resolution of detectors and suppression of background. We have not now enriched ^{130}Ba for planning investigation. Such isotope may not have enough radio-purity for the experiment.

The goal of the additional activity associated with **Obelix and Idefix** detectors is the search for 2vββ decay of ^{82}Se to excited states of ^{82}Kr, and investigations of 2vββ decay of ^{96}Zr to excited states of ^{96}Mo and 2vββ decay of ^{150}Nd to excited states of ^{150}Sm. Search for 2vββ decay of ^{82}Se is now in progress with the spectrometer Obelix (Fig.4) and ~6 kg of ^{82}Se with enrichment of 95(1)%. Up to now 2vββ decay of ^{82}Se to excited states of ^{82}Kr was not detected. According to our estimations, we can reach a level of sensitivity $T_{1/2}$~ 6 x 10^{22} years in 3 years of measurement, and according to theoretical predictions, we hope to detect this rare decay for the first time. Other investigations of enriched ^{96}Zr and ^{150}Nd will be performed using the Idefix detector, after installation it inside passive shielding, and detector Obelix, after finishing current measurement of ^{82}Se. For both mentioned it would be need to order the enriched ^{96}Zr and ^{150}Nd isotopes. Obelix and Idefix detectors were produced by the company of Canberra and are based on P-type crystals with the sensitive volume of ~600 cm^3. The mass of detectors are approximately 3.2 kg and the detector relative efficiency is ~160%. Crystals were mounted in ultra low background U-type cryostats. The energy resolution (FWHM) of the detectors are ~1.2 keV at 122 keV (^{57}Co) and ~2 keV at 1332 keV (^{60}Co). The energy threshold of the HPGe detectors is about 10 keV. The detector part of the Obelix cryostat is encircled by the passive shielding of several layers of Roman lead (PbI) and low-activity lead (PbII) (Fig.4).

Obelix and Idefix detectors are located in the deep underground laboratory (4800 m w.e.) which allows us to suppress cosmic rays and fast neutrons. Idefix still has no passive shielding. It has to be produced in the frame of current activity.

Expected results

In the frame of this project we hope to detect 2vββ decay of ^{82}Se to excited states of ^{82}Kr, detect 2vββ decay of ^{150}Nd to excited states of ^{150}Sm and 2vββ decay of ^{96}Zr excited states of ^{96}Mo.

Risks

Passive shielding of Idefix detector may not give a good suppression of background. We have not now enriched ^{150}Nd and ^{96}Zr for planning investigation. These isotopes may not have enough radio-purity for the planning measurements.

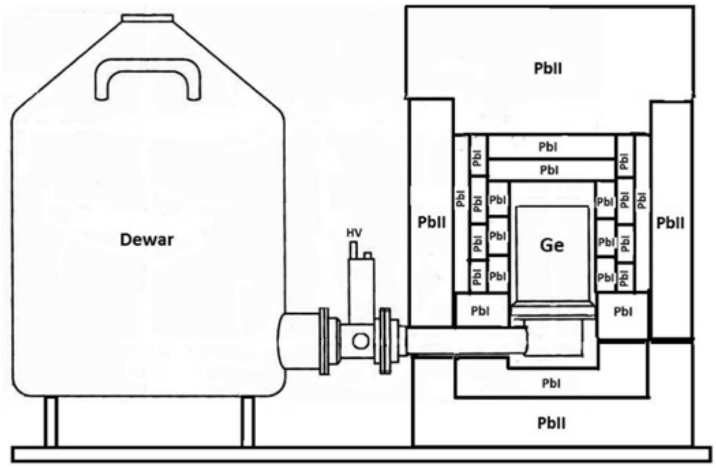

Fig.4. *HPGe detector Obelix in the passive shielding.*

The double beta decay experiments NEMO2/3 and **SuperNEMO** have been carried out with the active participation of DLNP JINR since 1992. The SuperNEMO project inherits a unique track calorimetric technique successfully proven in the NEMO-3 experiment, with improved detector performance and increased to 100 kg mass of ββ isotope. The objective of the SuperNEMO experiment is the direct search for neutrinoless double beta decay for several isotopes (initially for ^{82}Se) with the sensitivity allowing to reach the inverted neutrino-mass hierarchy.

Currently there are above 30 ongoing or proposed double beta decay experiments. One or more of them have good chances to detect 0νββ decay if the neutrino-mass hierarchy is the inverted one. Then verification of this break-through measurements by other experiments, using different nuclear sources, is needed. If/when detected, the 0νββ continues to attract interest beyond the first detection by verification by the other experiments and by attempts to unveil the mechanism(s) responsible for the decay. In this case, to determine the decay mechanism, a detector such as SuperNEMO is needed, unique in the field of experimental research of 0νββ due to its ability to completely reconstruct the topology of the event with the measurement of individual energies and the angular correlation of the emitted electrons.

Methods and approaches, methodologies

As stated above, SuperNEMO is the next generation 0νββ experiment, based on the advanced NEMO-3 combined track-calorimetry method. However, it has a planar geometry. SuperNEMO will consist of 20 identical modules, each containing ~5 kg of enriched double beta decay isotope. The main isotope under study is ^{82}Se, which can be relatively easily obtained in large quantities with high enrichment and a high degree of purification and, which is important, in real time. Methods are being developed for obtaining significant amounts of ^{150}Nd and ^{96}Zr, which are very interesting because they have a high $Q_{\beta\beta}$ value. The first SuperNEMO module (Demonstrator) is currently being commissioned in the Laboratoire Souterrain de Modane in the 4,800 m.w.e. deep Fréjus tunnel in France.

The SuperNEMO Demonstrator Module (Fig. 5) has a layered design, with foils of ββ emitter sandwiched between tracker modules, surrounded by calorimeter walls. The source isotope ^{82}Se is mixed in a PVA base to create thin foils, suspended from the source foil frame. The modular design allows us to change these foils to study other isotopes.

The tracker, constructed in four C-shaped sections, consists of 2034 3-metre long drift cells operating in Geiger mode, arranged in rows of nine cells on each side of the source foil. Each cell comprises a central anode wire surrounded by 12 field-shaping wires, with copper cathode end caps at either end. When a charged particle crosses the cell, the anode signal timing tells us the distance from the anode wire, while the relative timings of the cathode signals give a position along the wire, allowing three-dimensional reconstruction. The two calorimeter walls, situated outside the tracker, consist of 520 optical modules; 8-inch radiopure PMTs coupled to polystyrene scintillator blocks wrapped in teflon and mylar, with individual iron shielding.

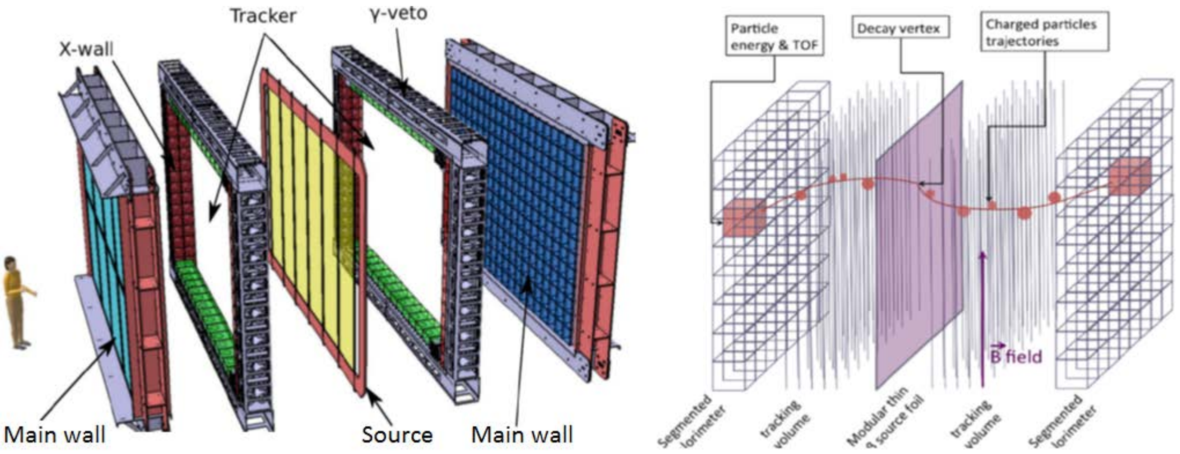

Fig 5: *Left: Pictorial view of the SuperNEMO Demonstrator Module. On each side of the source frame a tracker and a calorimeter module are installed. Right: Detection principle of SuperNEMO: trajectories of charged particles emitted from the source foils are measured in the tracker while their energy is deposited into one or more calorimeter modules.*

Lower-resolution optical modules around the edges of the tracker (giving 712 modules) offer 4π acceptance.

Expected results

In its initial running period of 2.5 years, the Demonstrator Module will have a $0\nu\beta\beta$ sensitivity to the $0\nu\beta\beta$ half-life of $T_{1/2} > 6 \times 10^{24}$ years, corresponding to a Majorana neutrino mass $\langle m_\nu \rangle < 200 - 400$ meV. The full SuperNEMO detector using 20 modules with an exposure of 500 kg years (5 years, 100 kg of ^{82}Se) would improve $0\nu\beta\beta$ sensitivity to $T_{1/2} > 10^{26}$ years, that corresponds to $\langle m_\nu \rangle < 50 - 100$ meV.

Besides the $0\nu\beta\beta$ searches, investigations of two-neutrino double beta decay of ^{82}Se to the ground and excited states of ^{82}Kr will be performed. New detailed study of $2\nu\beta\beta$ decay of ^{82}Se is of interest in particular from the point of view of the possibility to determine the effective axial-vector coupling g_A using measured spectra of individual electron energies.

Risks

The main issue for experiments to search for rare events is to provide low-background conditions. Beforehand, all structural materials of the SuperNEMO Demonstrator were tested using low-background HPGe detectors. Selenium was purified from radioactive impurities. All work on the production of source foils was carried out in a clean room with constant monitoring of dust and radon levels. The radiation purity of the source foils was assessed using a specially designed ultra-low-background BiPo-3 detector.

The radon concern is a general problem for all double beta decay experiments. To reduce the radon entering the tracker from outside, radon-free air from "antiradon factory" is flushed under the tent covering the detector. Special electrostatic detectors have been created to measure radon concentration in gas at the inlet and outlet of the volume of the track detector and for monitoring the radon in the air of the underground laboratory and under the anti-radon tent.

The success of measures to ensure low background conditions will be checked using the SuperNEMO detector itself, which is capable of identifying and measuring internal contamination of foils and backgrounds from sources external to foils.

Possible instability of the temporal and energy characteristics of the calorimeter can also lead to the appearance of background events imitating 0nbb decay. To overcome this problem, using the experience of the NEMO-3 experiment, periodic (every 3 weeks) absolute calibrations of the calorimeter using radioactive sources (^{207}Bi, ^{60}Co), as well as daily monitoring of the stability of the calorimeter using a laser system, are provided.

The goal of the **MONUMENT** (Muon Ordinary Capture for the Study of Nuclear Matrix Elements) project is to study ordinary muon capture (OMC) in isotopically enriched ^{96}Mo and ^{48}Ti. The method is based on the high-precision beam spectroscopy using high-purity germanium detectors. In addition, it is planned to obtaining the total and partial probabilities of OMC in lighter elements such as ^{56}Fe and ^{32}S, ^{12}C and ^{13}C. As well as, In addition, to obtain muonic X-ray spectra for the studied nuclei and add them to the existing electronic atlas of such spectra (http://muxrays.jinr.ru). To achieve the goals set, it is proposed to extend the program for another five years.

Methods and approaches, methodologies

The lifetime of the 0nbb depends not only on the effective Majorana mass of the electron neutrino and the phase space factor proportional to the decay energy, but also on the magnitude of the nuclear matrix element (NME) [Physics Pub. 1 edition. Bristol and Philadelphia, 1995 Vol. 1.]. If the phase space factor is considered to be known, then the NME calculation is the most difficult theoretical problem. In the most common case of double beta decay (**DBD**), the transition is occurred with a change of Z by two, via the virtual states of the intermediate nucleus. It creates additional difficulties for the calculations. However, one can try to populate the excited states of the intermediate nucleus in some other process which is complementary to the one being studied. Among processes that can be considered are, for example, charge-exchange reactions or ordinary muon capture (**OMC**) in a nucleus that is a daughter for the DBD nucleus. In the second case, an additional advantage could be the following one. Being a massive particle, muon transfers almost all its energy to the nucleus, feeding its excited levels up to a giant dipole resonance state. For this case the capture probabilities can be calculated using the same models as in the case of DBD, and at the same time be measured experimentally.

Thus, **OMC** is a unique way to study the wave functions of the excited states of the intermediate nucleus related to 0nbb decay. In [Czech.J.Phys. 56 (2006) 519, Phys. Rev C 100, 014619 (2019)], it was described how muon capture studies could be used to calculate NME, as well as to study the properties of neutrinos. In [Phys.Rep. 338 (2000) 265], a review of studies on ^{100}Mo is presented, which also describe the necessity for research in this area in order to study the astrophysical properties of neutrinos.

The idea of muon capture experiments is based on precise measurement of the time-energy distribution of γ-rays after muon capture. These distributions provide a wealth of experimental information, and all of them are useful inputs for NME calculations of DBD. The total rates of muon capture by specific isotopes are determined by analyzing the time distribution of delayed γ-rays. Using delayed γ-rays balance of intensities the partial probabilities of muon capture on the bound states of the daughter nucleus are extracted. Yields of short-lived isotopes are obtained using offline measurements. An important by-product of the measurements is meso-X-ray spectra. They are unremovable background in our measurements and are used for identification of the energy spectra, as well as for normalization. For continuation of the project it is proposed to make changes in the experimental setup, find the optimal parameters for investigation and more precise calculations of partial capture rates. The main approaches and methods for the task implementation:

1. Isotopically enriched elements as targets for muon capture. This method immediately eliminates other nuclei in the target, where muon capture followed by excitation of nucleus levels can occur. These levels are deexcitate by gamma rays emission with similar or the same energies that we are interested in;

2. Monochromatic and well-collimated beam of negative muons. The overwhelming part of the muons is captured exactly in the target (the beam of negative muons piE1 in PSI provides such a possibility with 10 kHz intensity at 28 MeV/c momentum);

3. Precise measurements of time and energy distributions of γ-rays by means of the various volumes germanium detectors set with high energy resolutions (see Fig. 6);

4. Due to excellent energy resolutions, it is possible to make precise identification of the transitions under study;

5. Data acquisition system (DAQ) using fast flash ADCs. The system has very short data transfer time and excellent timing. Application of the special trapezoidal filters allows to improve the energy resolution;
6. The muon counters (see Fig. 12), operating in anticoincidence and coincidence mode, makes it possible to determine the arrival time of a muon with 5 ns precision and separate prompt and delayed γ-rays signals;

7. The meso-X-ray spectra obtained with new data acquisition system (see Section 5) will contribute to the reliable identification of γ-lines and will also provide normalization by the number of muons stopped in a given chemical element to avoid another calculations of the absolute efficiency (the solid angle corrections) ;

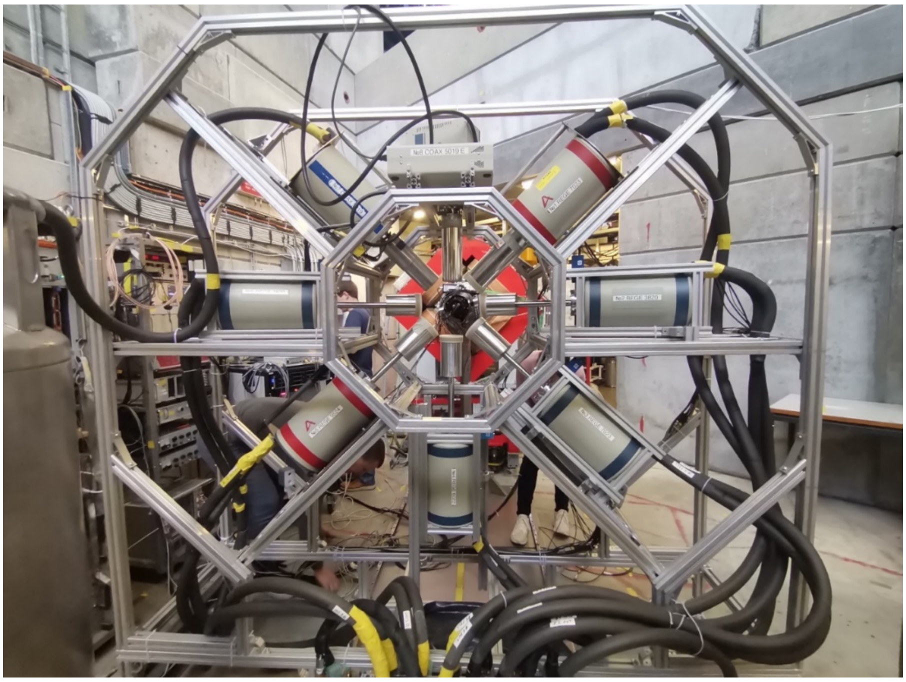

Fig. 6: *Experimental setup of the MONUMENT project.*

8. Off-line measurements will provide information about what/how many isotopes are produced as a result of muon capture. Such information is necessary to verify calculations of the partial capture rates in enriched isotopes.

Expected results

1. For the first time, the values of the OMC partial capture rates in the isotopes ^{136}Ba and ^{96}Mo will be obtained, which are the basis for new NME calculations for the double beta decay of ^{136}Xe and ^{96}Zr.
2. For the first time, the values of the total and partial OMC rates in the light ^{56}Fe and ^{32}S isotopes will be obtained, which are necessary for the interpretation and optimization of NME calculation models for 0νββ decay.
3. The values of the partial probabilities of OMC in the ^{100}Mo isotope will be obtained for the first time; this information very needful for calculating the NME from the point of view of the search for a supernova.

4. The previously obtained values of the total and partial capture rates in enriched ^{76}Se and ^{48}Ti isotopes will be refined; the new results will be compared with the theoretical calculations of NME, as well as their interpretation relative to various models.
5. The values of the yields of various isotopes produced of muon capture in the above targets will be obtained.

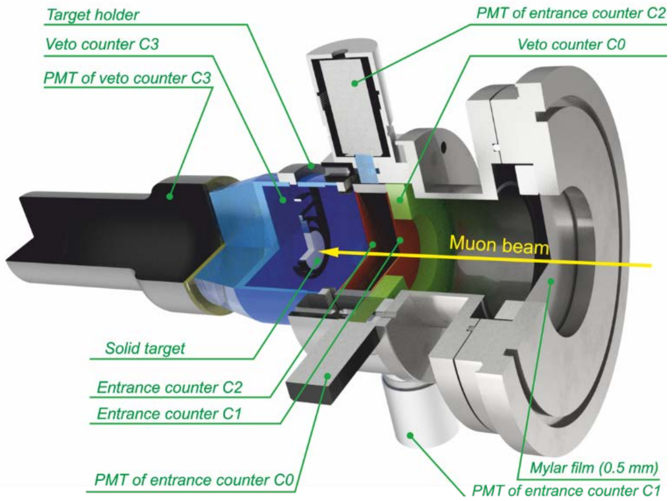

Fig. 7: *Muon trigger system in the MONUMENT project*

6. The obtained muonic X-ray spectra of the studied targets will complement the existing electronic library of muX spectra created in our department (http://muxrays.jinr.ru) and used by groups associated with muon physics.
7. The results obtained will be published in leading Russian and foreign scientific journals, as well as presented at international conferences.

Risks

- a sharp decrease in the detector's efficiency in the energy region above 3-4 MeV (this point can be improved using modern high-volume HPGe detectors);
- the large contribution of the statistical uncertainty in the balance of the intensities of the partial probabilities of OMC to the bound states of the daughter nucleus (this issue can also be solved by using inverted coaxial detectors with better resolution and the possibility of signal separation by pulse-shape analysis);
- imperfection of the calculated NME models for muon capture at the moment, which may cause an incorrect interpretation of the experimental results from the point of view of the calculated models.

In the coming years, only earlier measurements on charge-exchange (n,p) and (p,n) reactions could constitute potential competition for our project. But, as mentioned above (see sec. 2.1), at the moment there is no reliable information about the existence of such experiments as (n,p) reactions (checking the "right leg", as in the case with OMC). Moreover, the actual contribution to the NME calculations, at least for the neutrinoless double beta decay mode, has not been justified to date.

The project is continuation of the **EDELWEISS** scientific program conducting by JINR in the international collaboration from 2005. Direct search for DM is the fundamental scientific problem addressed by the EDELWEISS.

There are strong evidences of the existence of non-baryonic DM at almost every cosmic scale. Theories and simulations regarding hierarchical structure formation indicate that this non-luminous component may manifest itself in the form of a gas of Weakly Interacting Massive Particles (WIMPs). There is no viable candidate in the Standard Model for the composition of this cold DM. It is very intriguing that the most favored solution to the problem of hierarchy in particle physics, SUSY, predicts that the Universe is filled with WIMPs. Natural candidates, like the neutralino, have a predicted mass in the range of a few GeV/c^2 to TeV/c^2 and an elastic scattering cross section on nucleons at the weak scale. Furthermore, they are characterized by a dominant interaction with atomic nuclei, inducing low-energy nuclear recoils in the target material, and could be thus detected in the so-called direct detection experiments. There is an intense experimental activity on the direct detection since many years, for which the most promising results have been obtained with liquid noble and cryogenic detectors.

In the present time there is an increasing gain of interest for the search of low-mass WIMPs and other DM particles (axions, etc) arising on the one hand from no observation yet of SUSY at the LHC and on the other hand from new theoretical approaches favouring lighter candidates. As an example, asymmetric DM models linking the relic density to the baryon asymmetry predict DM particles with masses of a few GeV/c^2. The EDELWEISS experiment originally designed for the search of WIMPs of O(100 GeV/c^2) has undergone a redirection of its strategy to optimization of used detectors for low-mass (light) WIMP searches.

Methods and approaches, methodologies

The EDELWEISS searches for DM using an array of cryogenic germanium bolometers with phonon and ionization channels, it thus able to identify events induced by nuclear recoils. During the previous EDELWEISS phase un unprecedented charge resolution of 0.53 electron-hole pairs (RMS) has been achieved using the Neganov-Trofimov-Luke (NTM) internal amplification. With this the experiment set the first Ge-based constraints on sub-MeV/c^2 DM particles interacting with electrons, as well as on dark photons down to 1 eV/c^2 [Phys. Rev. Lett. 125, 141301]. These results demonstrate the high relevance of cryogenic Ge detectors for the search of DM interactions producing eV-scale electron signals. The region of "light WIMPs" could be further investigated in the EDELWEISS experiment thanks to advantage of energy resolution below 20 eV reachable with new HPGe bolometers. This stage is in the R&D phase, it is devoted to building of improved detectors, their holders and supports, improvement of the background and acquisition. The EDELWEISS experiment is installed in the deep underground laboratory, the Laboratoire Souterrain de Modane (LSM). Its detectors cooled down to cryogenic temperatures (~20 mK) in order to perform a simultaneous measurement of ionization and heat signals. Charge collection is carried out by concentric electrodes interleaved on all the absorber surfaces. The readout of the four types of electrodes allows fiducial selection of events and results in a crucial background rejection for surface α- and β-events. The unlimited target of current R&D and measurements in the EDELWEISS experiment is achievement of sensitivity to light WIMPs, that will also allow detection of B-8 solar neutrinos through coherent neutrino-nucleus scattering (CEνNS).

The project is the transformation phase, when the old setup used from 2005 start to be decommissioned with the aim to have smaller low level background setup with new generation of the cryosystem that allowed timely execution of intensive r&d program. For few next years the EDELWEISS detectors will be hosted by BINGO setup (development of the CUPID-Mo programm, that has been hosted by the EDELWEISS). The objective is to find the source and discriminate so-called “heat only” background events and further improve the energy resolution of the ionization channel. New detector electrodes design, the thermal sensors (NTD and TES) will be tested with aim to have near zero-free background in the lowest energy region (i.e. at below 100 eV).

JINR team is expected to contribute to the projects in the following: 1) Development of new low threshold Ge detectors; Assembly and commissioning; 2) New cryosystem development and running; 3) Development of methods for low background measurements; 4) Data taking (this includes daily routine procedures, as well as regular and special calibration runs); 5) Low background study and development of methods of neutron and radon detection; 6) Detector simulations and data analysis; Publication of results.

The JINR team has the following resources at the LSM: several low background neutron detectors of different design (He-3, NaI based), alpha-chamber, two highly sensitive and low background radon detectors, two HPGe spectrometers (160% relative efficiency) for material radioactivity screening.

Expected results

Further ahead the requirements to the EDELWEISS will to approach the neutrino floor, which corresponds to the coherent scattering of neutrinos from several astrophysical sources as solar ^{8}B neutrinos. Fig. 9 shows sensitivity projections derived from the likelihood analysis for a large exposure of 50000 kg d and resolutions of both heat and ionization channels at 100 eV. Limits are computed for both 8 V and 100 V bias voltages and plotted in purple and black, respectively. Solid lines correspond to the expected limits achievable considering the current EDELWEISS background budget, with the exception of heat-only events, which are supposed to be completely suppressed.

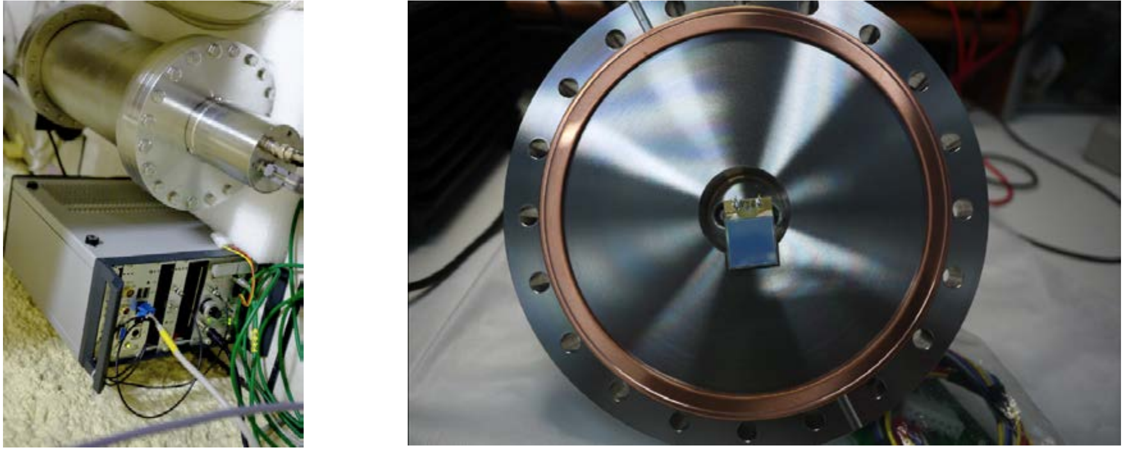

Fig. 8: *Mobile high sensitive radon detection system developed by JINR.*

Thick dashed lines (dot dashed lines) are obtained assuming not only no more heat-only events (a reduction of heat-only events by a factor 100), but also no more neutrons and a reduction of the Compton background by a factor 10 (R&D for new materials, shields, the cryosystem). The background-free sensitivity is shown in thin dashed lines.

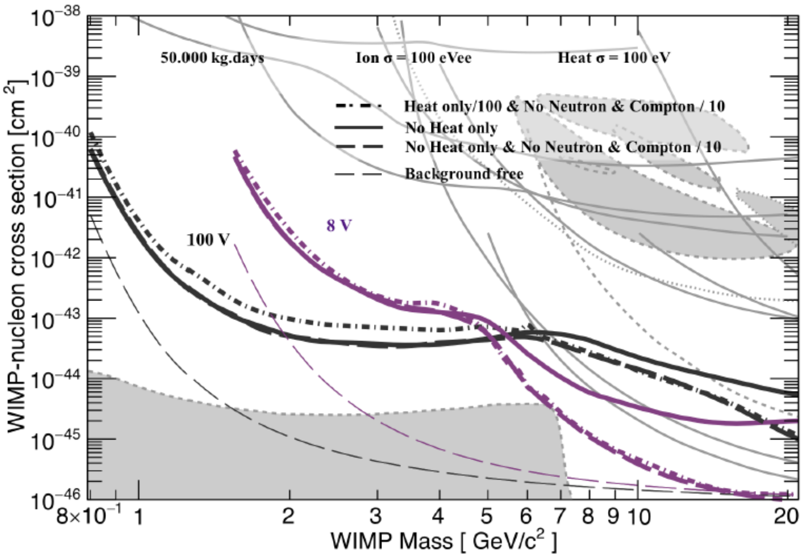

Fig. 9: *Projected sensitivities for a large exposure of 50 000 kg d with strongly improved background levels and R&D upgrade performance achieved, with baseline resolutions of heat and ionization channels at 100 eV. Limits are computed using a likelihood analysis at 8 V (purple) and 100 V (black) assuming a suppression of the heat-only background (solid line), and no more neutron background associated with a reduction of the Compton background by a factor 10 (thick dashed line). The background-free sensitivity is shown in thin dashed lines.*

Risks

The schedule of the EDELWEISS project can be significantly affected due to factors connected to stability of running of all components of the experiment including cryosystem with dilution cryostat and its stability, electronics, acquisition system, subsystems. Though failure of different components of the setups is difficult to predict, the collaboration already accumulated more than 20 years of running of the cryogenic setups, with accumulated experience in fixing of arising problems including problems with the cryosystem in short time.

One of critical part of any low background experiment is avoiding of its contamination from outside. The trace activities on unacceptable level can be accumulated due to calibrations with not properly tested (on radioactive leak and integrity) radioactive sources, due to radon and other radioactive gases in atmosphere, due to dust and dirt. To avoid these problems a set of special procedures is in place during all stages of experiment starting from the detector production to calibration measurements. Only specially certified materials can be entered into the clean room surrounding the setup. All works performed in the clean room are under continuous control of dust and radon level. Only double encapsulated and properly tested radioactive sources are used for calibrations.

Now, let us consider some of the scientific challenges: the main challenge for EDELWEISS rare-event search experiments is to distinguish a DM signals from recoils induced by natural radioactivity, cosmic rays and other sources. In other words, the most important problem is the background. Thus, the key to the success of the experiments is the possibility to identify with high efficiency the background events, which can mimic the signal. The EDELWEISS experiment together with traditional methods of background reduction uses several special methods for discrimination of backgrounds (heat/ionization measurements, FID detectors for discrimination of surface events, PSD for reduction of the noise). Additionally, the background is independently controlled with supplementary detectors. Several more such detectors are under development at JINR.

2.3 Estimated completion date

The term of the project extension is 5 years; it is supposed to continue it further depending on the results obtained

LEGEND (2024-2045)

2024: Adding of newly produced detectors to LEGEND-200 to reach the final mass of ^{76}Ge of 200 kg. Restart data taking. Taking the decision about the host lab for LEGEND-1000. Finalizing the CDR of LEGEND-1000.

2024-2031: Data taking in LEGEND-200. R&D for LEGEND-1000 hardware components (detector holders, ASICs, lock system, LAr instrumentation, etc.). Start production and acceptance of the new enriched Ge detectors and installation of the LEGEND-1000 facility at the host lab.

2031-2035: Disassembly of LEGEND-200. Installation of detectors and LAr instrumentation in LEGEND-1000 and start data taking.

2035-2045: Data taking in LEGEND-1000.

All years: data analysis, preparation of publications.

TGV

2024 year: Update of TGV spectrometer (detector part and electronics).
2024-2025 years: Measurement of enriched ^{106}Cd.
2026 year: Measurement of TGV background without samples. Buying of enriched ^{130}Ba, testing its radio purity, purification of enriched isotope from radioactive contamination, production of samples for investigation in the TGV experiment.
2027 year: Installation samples of ^{130}Ba in TGV spectrometer.
2027-2028: Measurement of ^{130}Ba

Obelix&Idefix:

2024 year: Installation Idefix detector in passive shielding
2024-2025 years: Measurement of enriched ^{82}Se.
2025 Measurement of background of Obelix and Idefix detectors.
2025 Buying of enriched isotopes ^{96}Zr and ^{150}Nd, testing their radio purity, purification of enriched isotopes from radioactive contamination, preparation of samples
2026 year: Search for resonant 0νECEC decay of ^{106}Cd
2026-2028: Investigation of double beta decay of ^{96}Zr and ^{150}Nd using Obelix and Idefix detectors

SuperNEMO:

2024 year: Completion of the data taking with SuperNEMO Demonstrator in a configuration without passive protection. Installation of passive shielding of the detector (borated paraffin + borated water + low background iron) and installation of the anti-radon tent.

2025-2027 year: data taking with SuperNEMO Demonstrator in a full configuration with passive shielding and anti-radon tent.

2026-2028 year: based on the results of Demonstrator Module CDR for the next SuperNEMO phase.

MONUMENT

2024: it is planned to carry out measurements of muon capture with gas targets of carbon enriched in atomic masses 12 and 13;

2024-2027: investigation of light nuclei in terms of validation of theoretical models applicable to double beta decay as well as enriched 96Mo; R&D on the application of muon capture in other areas related to physics, such as radiobiology and mesochemistry;

2025-2028: Based on R&D, preparation of CDRs for the new MONUMENT phase.

Throughout the life of the project, we will continue to study and improve the experimental facility and conduct R&D for further phases of the experiment.

All years: data analysis, preparation of publications.

EDELWEISS

2024 year: The current EDELWEISS setup will be completely decommissioned at the LSM site. Commissioning of the BINGO setup and implementation of new EDELWEISS detectors into the setup.

2024-2027 year: R&D to search the nature of the heat only events in the bolometers. Simultaneous search for light DM candidate.

2025-2028 year: based on the R&D results CDR for new generation of the next EDELWEISS phase.

During all time of the project we will continue to study the setup environmental background, perform intensive calibration program and R&D for further experiments.

All years: data analysis, preparation of publications.

2.4 Participating JINR laboratories

DLNP

2.4.1 MICC resource requirements

Computing resources	Distribution by year				
	1st year	2nd year	3rd year	4th year	5th year
Data storage (TB) -> EOS, Tapes	EOS - 100	EOS - 100	EOS - 100	EOS - 100	EOS - 100
Tier 1 (CPU core hours)					
Tier 2 (CPU core hours)					
SC Govorun (CPU core hours)					
Clouds (CPU cores)					

2.5. Participating countries, scientific and educational organizations

Organization	Country	City	Participants	Type of agreement
TUM	Germany	Munich	S. Schoenert + 7 FTE	Scientific collaboration agreement
MPIK	Germany	Heidelberg	B. Schwingenheuer + 2 FTE.	Scientific collaboration agreement
LNGS	Italy	Assergi	M. Laubenstein + 2 FTE	
UoT	Germany	Tubingen	J. Jochum + 2 FTE	
UZH	Switzerland	Zurich	L. Baudis + 2 FTE	
UNC	USA	Chapel-Hill	J. Wilkerson + 3 FTE	
Paul Sherrer Insitute (PSI)	Switzerland	Villigen	A.Knecht + 1 FTE	Scientific collaboration agreement
Department of Physics and Astronomy, University of Alabama	USA	Tuscaloosa	I.Ostrovskiy + 1 FTE	
KU Leuven, Institute for Nuclear and Radiation Physics	Belgium	Leuven	T. Cocolios + 1 FTE	
Univ Lyon, Universite Lyon 1, CNRS/IN2P3, IP2I-Lyon	France	Lyon (Villeurbanne)	Gascon J. + 13 FTE	Scientific collaboration agreement
Centre de Spectroscopie Nucleaire et de Spectroscopie de Masse, IN2P3-CNRS, Universite Paris XI	France	Orsay	Marnieros S. + 8 FTE (EDELWEISS), Sarazin X. + 10 FTE (SuperNEMO)	
Institut Néel	France	Grenoble	Benoit A. + 1 FTE	
Université Paris-Saclay	France	Orsay	Jin Y.	
CEA	France	Gif-sur-Yvette	Armengaud E. + 5 FTE	
University of Edinburgh	UK	Edinburg	Berschauer C. + 5 FTE	

The University of Warwick	UK	Warwick	Mitra F. + 2 FTE	
Wakasa Wan Energy Research Centre	Japan	Fukui	Suzuki K.	
Imperial College London	UK	London	Franchini P. + 1 FTE	
Institute for Theoretical and Experimenal Physics	Russia	Moscow	Barabash A. + 2 FTE	
Osaka University	Japan	Osaka	Nomachi M.	
The University of Manchester	UK	Manchester	De Capua S. + 6 FTE	
The University of Texas at Austin	USA	Austin	Cesar J. + 3 FTE	
University College London	UK	London	Attree D. + 23 FTE	
CPPM, Centre de Physique des Particules de Marseille	France	Marcel	Busto J. + 2 FTE	Scientific collaboration agreement
Charles University, Prague	Czech Republic	Prague	Vorobel V. + 1 FTE	
Comenius University, Bratislava	Slovakia	Bratislava	Simkovic F. + 4 FTE	
Chech Technical University in Prague	Czech Republic	Prague	Stekl I. + 8 FTE	
LP2I-Bordeaux	France	Baurdeaux	Piquemal F. + 5 FTE	
LPS CAEN	France	Caen	Depreaumont H. + 7 FTE	
LAPP	France	Ancy	Chabanne E. + 6 FTE	
Idaho National Laboratory	USA	Idaho	Caffrey G. + 2 FTE	

2.6. Key partners *(those collaborators whose financial, infrastructural participation is substantial for the implementation of the research program. An example is JINR's participation in the LHC experiments at CERN).*
DoE, USA
Technische Universität München (TUM), Germany

3. Manpower

3.1. Manpower needs in the first year of implementation

№№ n/a	Category of personnel	JINR staff, amount of FTE	JINR Associated Personnel, amount of FTE
1.	research scientists	16.95	--
2.	engineers	3.55	--
3.	specialists	1	—
4.	office workers	0	—
5.	technicians	0.5	—
	Total:	**22**	

3.2. Available manpower

3.2.1. JINR staff

No.	Category of personnel	Full name	Division	Position	Amount of FTE
1.	research scientists	Belov V.	SEDNS&RC	research scientist	0,5
		Vaganov Yu.	SEDNS&RC	research scientist	0,2
		Vasiliev S.	SEDNS&RC	senior scientist	0,5
		Vorobyeva M.	SEDNS&RC	research scientist	0,1
		Gurov Yu.	SEDNS&RC	head of the sector	0,7
		Gusev K.	SEDNS&RC	senior scientist	0,8
		Zhitnikov I.	SEDNS&RC	research scientist	0,2
		Zinatulina D.	SEDNS&RC	senior scientist	1
		Inoyatov A.	SEDNS&RC	head of the sector	0,3
		Kazarcev S.	SEDNS&RC	junior scientist	0,5
		Karaivanov D.	SEDNS&RC	senior scientist	0,1
		Kartvtsev O.	SEDNS&RC	senior scientist	0,5
		Klimenko A.	SEDNS&RC	senior scientist	1

		Kochetov O.	SEDNS&RC	senior scientist	1
		Lybashevsky A.	SEDNS&RC	head of the sector	0,1
		Mirzaev N.	SEDNS&RC	junior scientist	0,2
		Morozov V.	SEDNS&RC	chief scientist	0,2
		Ponomarev D.	SEDNS&RC	junior scientist	0,4
		Rakhimov A.	SEDNS&RC	research scientist	0,2
		Rozov S.	SEDNS&RC	deputy head of department	0,2
		Rumyantseva N.	SEDNS&RC	research scientist	1
		Rukhadze N.	SEDNS&RC	senior scientist	1
		Salamatin A.	SEDNS&RC	senior scientist	0,3
		Salamatin D.	SEDNS&RC	junior scientist	0,1
		Sandukovskiy V.	SEDNS&RC	consultant at the directorate of the DLNP	0,25
		Smolnikov A.	SEDNS&RC	senior scientist	1
		Sushenok E.	SEDNS&RC	research scientist	1
		Temerbulatova N.	SEDNS&RC	junior scientist	0,1
		Timkin V.	SEDNS&RC	research scientist	0,5
		Tretyak V.	SEDNS&RC	senior scientist	1
		Trofimov V.	SEDNS&RC	research scientist	0,4
		Filosofov D.	SEDNS&RC	head of the sector	0,1
		Fomina M.	SEDNS&RC	research scientist	0,3
		Shirchenko M.	SEDNS&RC	senior scientist	0,4
		Shitov Yu.	SEDNS&RC	senior scientist	0,5
		Yakushev E.	SEDNS&RC	head of department	0,2
		Nemchenok I.	SEDNS&RC	head of the	0,1

				group	
2.	engineers	Abd A.M.A.M.	SEDNS&RC	engineer	0,1
		Aksenova Yu.	SEDNS&RC	engineer	0,5
		Alekseesv I.	SEDNS&RC	senior engineer	0,3
		Vagina O.	SEDNS&RC	engineer	0,3
		Volnykh V.	SEDNS&RC	lead engineer	0,25
		Dotsenko I.	SEDNS&RC	senior engineer	0,1
		Kalinova B.	SEDNS&RC	engineer	0,2
		Kamnev I.	SEDNS&RC	engineer	0,2
		Katulin S.	SEDNS&RC	senior engineer	0,1
		Katulina S.	SEDNS&RC	senior engineer	0,2
		Fateev S.	SEDNS&RC	engineer	0,1
		Shakhov K.	SEDNS&RC	engineer	0,1
		Shevchenko M.	SEDNS&RC	engineer	0,3
		Shevchik E.	SEDNS&RC	senior engineer	0,5
		Sherbakova I.	SEDNS&RC	engineer	0,3
3.	specialists	Kulkova E.	SEDNS&RC	document management specialist	0,1
		Lednicka T.	SEDNS&RC	laboratory assistant	0,1
		Morozova T.	SEDNS&RC	senior inspector	0,3
		Khusainov T.	SEDNS&RC	laboratory assistant	0,5
4.	technicians	Emeliyanov A.	SEDNS&RC	mechanic-repairman	0,2
		Zaikin A.	SEDNS&RC	mechanic of experimental stands and setups	0,1

		Fariseeva V.	SEDNS&RC	senior technician	0,2
	Total:	**59**			**22**

3.2.2. JINR associated personnel

No.	**Category of personnel**	**Partner organization**	**Amount of FTE**
1.	research scientists	-	-
2.	engineers	-	-
3.	specialists	-	-
4.	technicians	-	-
	Total:		

4. Financing

4.1 Total estimated cost of the project/LRIP subproject

The total cost estimate of the project (for the whole period, excluding salary).
The details are given in a separate table below.

3 000 000 $

4.2 Extra funding sources

Expected funding from partners/customers – a total estimate.

Grant RFBR (4 000 000 rubles, last year funding 2023)

Project (LRIP subproject) Leader __________/___________/

Date of submission of the project (LRIP subproject) to the Chief Scientific Secretary: _________
Date of decision of the laboratory's STC: _________ document number: _________

Year of the project (LRIP subproject) start: ________________

(for extended projects) – Project start year: _______

Proposed schedule and resource request for the Project / LRIP subproject

Expenditures, resources, funding sources			**Cost (thousands of US dollars)/ Resource requirements**	**Cost/Resources, distribution by years**				
				1st year	2nd year	3rd year	4th year	5th year
		International cooperation	550	110	110	110	110	110
		Materials	550	110	110	110	110	110
		Equipment, Third-party company services	1500	300	300	300	300	300
		Commissioning	100	20	20	20	20	20
		R&D contracts with other research organizations	50	10	10	10	10	10
		Software purchasing	100	20	20	20	20	20
		Design/construction	50	10	10	10	10	10
		Service costs (*planned in case of direct project affiliation)*	100	20	20	20	20	20
Resources required	**Standard hours**	Resources						
		– the amount of FTE,	22	22	22	22	22	22
		– accelerator/installation,	-	-	-	-	-	-
		– reactor,…	-	-	-	-	-	-
Sources of funding	**JINR Budget**	JINR budget *(budget items)*	3000	600	600	600	600	600
	Extra fudning (supplementary estimates)	Contributions by partners Funds under contracts with customers Other sources of funding	-	4 M₽ (RFBR)	-	-	-	-

Project (LRIP subproject) Leader__________/__________________/

Laboratory Economist __________/__________________/

APPROVAL SHEET FOR PROJECT

Nuclear spectrometry for the search and investigation of rare phenomena

03-2-1100-2010/2024

Daniya Zinatulina

AGREED

JINR VICE-DIRECTOR	____________ SIGNATURE	____________ NAME	____________ DATE
CHIEF SCIENTIFIC SECRETARY	____________ SIGNATURE	____________ NAME	____________ DATE
CHIEF ENGINEER	____________ SIGNATURE	____________ NAME	____________ DATE
LABORATORY DIRECTOR	____________ SIGNATURE	____________ NAME	____________ DATE
CHIEF LABORATORY ENGINEER	____________ SIGNATURE	____________ NAME	____________ DATE
LABORATORY SCIENTIFIC SECRETARY THEME / LRIP LEADER	____________ SIGNATURE	____________ NAME	____________ DATE
PROJECT / LRIP SUBPROJECT LEADER	____________ SIGNATURE	____________ NAME	____________ DATE
APPROVED BY THE PAC	____________ SIGNATURE	____________ NAME	____________ DATE