Non-Accelerator Neutrino Physics and Astrophysics

2021/2022

Opportunities for postgraduate studies

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DZHELEPOV LABORATORY of NUCLEAR PROBLEM

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JOINT INSTITUTE FOR NUCLEAR RESEARCH

JINR

Department of Nuclear Spectroscopy and Radiochemistry

We at

Are you a graduate of the physics department of a university and are eager to discover your talent in the field of modern fundamental physics? Then the execution of the Ph.D. work on the scientific theme **“Non-Accelerator Neutrino Physics and Astrophysics (NANP&A)”** is a great chance for you! This topic performed in the **Department of Nuclear Spectroscopy and Radiochemistry**, DNLP, JINR is devoted to search and investigation of rear processes by means of nuclear physics methods.

Where to study? The department has 50 years of experience in high-precision nuclear spectroscopy using semiconductor, scintillator and other types of detectors in general and 30 years of experience in rare processes studies in different underground environments. The department has the knowledge, personnel and capabilities to create world-class facilities, conduct measurements with them and obtain world-leading results. The following resources are available to carry out the scientific projects: the laboratory for the production and repair of semiconductor detectors; laboratory for creation and production of scintillation materials for detectors; radiochemical sector (creation of calibration radioactive sources, purification of materials designated for low-background measurements from their contamination by natural radioactivities, etc.), mechanical workshops, a group of computer support, a group of mass separators and others.

What to study? At present, the theme consists of **seven main projects**, which includes world-leading experiments targeted topical and hot problems of fundamental physics:

- Studies of ultrahigh energy cosmic rays by deep-water telescope (**BAIKAL-GVD**)
- Search for neutrinoless double beta decay (**LEGEND, SuperNEMO, MONUMENT, TGV**)
- Measurements of reactor antineutrinos (**DANSS**)
- Search for coherent elastic neutrino scattering on nuclei and magnetic moment of neutrino (**GEMMA/νGEN/RICOCHET**)
- Search for dark matter (**EDELWEISS/RICOCHET**)
- Measurement of rare processes & low levels of radioactive background (**OBELIX**).

What I will get? You will have a unique opportunity:

- To get a brilliant start to a scientific career thanks to join work with leading physicists from around the world.
- To work in international collaborations on the edge of modern physics.
- To work in advanced facilities.
- To publish solid papers.
- To obtain fundamental world-class results in the field of neutrino physics.
- To get excellent material for thesis.

Experimental search for neutrinoless double beta decay of ^{76}Ge

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Experiment. The LEGEND experiment is designed to search for neutrinoless double beta (0νββ) decay of ^{76}Ge. LEGEND will operate with bare germanium semiconductor detectors (enriched in ^{76}Ge) directly immersed in liquid argon instrumented to readout argon scintillations for vetoing background events. Thanks to this approach in the predecessor GERDA experiment the background level was reduced down to the unprecedented value of 5×10^{-4} counts keV^{-1} kg^{-1} yr^{-1}. For further reduction of the background in the LEGEND experiment, our JINR group together with international collaborators is constantly performing the R&D for novel germanium detector types, new ultra-low background construction materials and the effective methods of argon scintillation readout. Our group has solid experience achieved at the design, preparation and integration phases of the GERDA experiment as well as during operating of the experiment and the analysis of data. This will help JINR group to keep the strong position in the LEGEND project. However, we are willing to enlarge the analysis part of our group – so we are looking for candidates who will work mainly for the modelling and data analysis. LEGEND is truly worldwide collaboration includes about 240 scientists from 47 institutions. The especially good connection our group has with the Technical University of Munich (Germany) and Max Planck Institute for Nuclear Physics, Heildelberg (Germany), so some working visits there are expected as well as to Gran Sasso National Laboratory in Italy, where the first phase of LEGEND will take place. The successful candidates are expected to join the international LEGEND data analysis team.

Supervisor's specific requirements: A master degree in particle or nuclear physics; programming skills; the experience with data analysis; good communication skills (English) and readiness to travel.

Possible themes for PhD thesis: such a low background experiment as LEGEND should allow searching not only for 0νββ decay of ^{76}Ge, but also for many other rare processes and exciting particles (like Super-WIMPs [2]). Therefore, depending on your choice, you will have a unique opportunity either to join the common 0νββ analysis and defend your PhD, for example, on a background model or perform your own search (!) for one of dozens of intriguing decays and/or particles.

Publications & links:

1. «Final Results of GERDA on the Search for Neutrinoless Double-β Decay», **PRL** 125 (2020) 252502. http://dx.doi.org/10.1103/PhysRevLett.125.252502
2. «First Search for Bosonic Superweakly Interacting Massive Particles with Masses up to 1 MeV/c^2 with GERDA», **PRL** 125 (2020) 011801. http://dx.doi.org/10.1103/PhysRevLett.125.011801
3. «Probing Majorana neutrinos with double-β decay», **Science** 365 (2019) 1445. http://dx.doi.org/10.1126/science.aav8613
4. «Improved Limit on Neutrinoless Double-β Decay of ^{76}Ge from GERDA Phase II», **PRL** 120 (2018) 132503. https://doi.org/10.1103/PhysRevLett.120.132503
5. «Upgrade for Phase II of the GERDA Experiment», EPJC 78 (2018) 388. https://doi.org/10.1140/epjc/s10052-018-5812-2
6. «Background-free search for neutrinoless double-β decay of ^{76}Ge with GERDA», **Nature** 544 (2017) 47. http://dx.doi.org/10.1038/nature21717
7. More info and full list of publications at GERDA and LEGEND pages.

DANSS

Studies of reactor antineutrinos

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Experiment. The compact and safe neutrino spectrometer DANSS based on plastic scintillators (PS) with a sensitive volume of 1 m^3 has been developed and created, capable of registering reactor antineutrinos. The spectrometer is mounted at the fourth power unit of the Kalinin NPP under the WWER1000 reactor (P_T^{HERM} = 3.1 GW). The lifting platform allows to move the spectrometer vertically by 2 meters online, providing a measurement within 10-12 m range, which is record short distance from the core of an industrial reactor. A high degree of segmentation and the use of a combined active and passive protection provides an excellent background suppression when registering ~ 5000 antineutrinos per day. The main objectives of DANSS are to search for oscillations in sterile neutrinos (fundamental task) and to demonstrate the possibility of monitoring a nuclear reactor for nonproliferation purposes (applied task). At the moment we are constructing a new modernized spectrometer DANSS-2, with which the Ph.D. student's work will be connected.

Requirements for candidate: background in nuclear and computer physics together with programming skills (algorithms, OOP, C++, Python) are required, knowledges of ROOT, GEANT4, machine (deep) learning techniques and Big Data processing would be great advantage!

Possible themes for PhD thesis:

- *Analysis of the backgroundы and signal in the DANSS-2 spectrometer* - the work is connected with the processing of data that will be obtained on the DANSS-2 spectrometer. It is necessary to analyze background patterns and assess various backgrounds, as well as to search for optimal selection criteria of signal selection. Application of new machine learning technologies for data analysis.
- *Investigation of the DANSS-2 sensitivity to sterile neutrino oscillations*. Determination of sensitivity and exclusion areas for the DANSS spectrometer based on modern methods of statistical analysis. Simulation of the experiment and comparison with real data.
- *Muon tomography of the reactor using a DANSS-2 spectrometer*. Along with the registration of neutrinos, the DANSS spectrometer is a precision detector of cosmic muons (tracks are recorded), which makes it possible to analyze this interesting channel.

Publications & links:

1. I.G. Alekseev et al., DANSS: Detector of the reactor AntiNeutrino based on Solid Scintillator, JINST 11 (2016) no.11, P11011, DOI: 10.1088/1748-0221/11/11/P11011, private copy https://clck.ru/TdZgb.
2. Full list of publications - https://clck.ru/TdZqG and presentations - https://clck.ru/TdaLN.
3. DANSS @ NEUTRINO-2020: slides https://clck.ru/TdaCv and video https://clck.ru/Tda99.

Muon Ordinary capture for the NUclear Matrix elemENTs in ββ decays

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Experiment. The purpose of the project is carrying out experimental measurements of muon capture at several daughter candidates for 0νββ decay nuclei. Obtained results would be drastically important for checking the accuracy of theoretical calculations of nuclear matrix elements (NME). Our group, together with colleagues from other institutes are going to make measurements of ordinary muon capture (OMC) on several isotopes on a meson-factory of the Paul Scherrer Institute (PSI) in Switzerland. First beam time will be done in 2021 for a preliminary study of ^{136}Ba (daughter nucleus for ^{136}Xe). The measurement program is planned for at least three years.

This project continues and extends the previous OMC program (1998-2006) made at the DNSR. Therefore a wealth of experience has been accumulated in the field of OMC studies. Throughout the period from 2021 to 2023, it is planned to perform OMC measurements for ^{136}Ba, ^{76}Se and ^{96}Mo isotopes. 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. In addition, we are going to measure and obtain results for OMC in ^{32}S, ^{40}Ca, ^{56}Fe and ^{100}Mo isotopes. These results are important for the experimental verification of theoretical calculations and may also be useful for astrophysics.

The MONUMENT is an international collaboration with about 25 participants from 7 countries. The JINR team needs a PhD student to be occupied with the process modeling and data analysis.

Requirements for candidate: Knowledge of C++ programming language, the ROOT and GEANT4 software are necessary.

Possible themes for PhD thesis:

- *Study of OMC in light nuclei.* You will do data analysis of particular nuclei, sorting raw data, obtaining spectra, identifying multiple processes involved and determining the OMC parameters.
- *Simulation of the OMC and experimental conditions of the OMC experiments.* Here it is necessary to simulate the OMC process, to compare the calculated and experimental data. Simulations are also necessary for planning future experiments - target optimization, beam conditions (profile & time distribution), search for optimal parameters and estimation of exposure required.

Publications & links:

1. D. Zinatulina et al., Ordinary muon capture studies for the matrix elements in ββ decay, PRC 99 (2019) 024327.
2. The Catalog of muon x-rays. http://muxrays.jinr.ru/
3. V.V. Belov et al., Construction of the Gaseous and Solid-State Targets for the Muon Capture Measuring System in ^{130}Xe, ^{82}Kr, and ^{24}Mg, Physics of Part. and Nucl. Lett. 17(6) (2020) 848-855.

νGeN

Search of CEνNS at nuclear reactor

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Experiment. The νGeN project is aimed to investigate fundamental properties of neutrino at close vicinity of the 3.1 GW reactor core of Kalinin Nuclear Power Plant (KNPP). The project mainly focused on a search for the coherent elastic neutrino nucleus scattering (CEνNS) and Neutrino Magnetic Moment (NMM). The previous phase of the project (GEMMA-I) sets up the current world's best upper limit for the NMM of $< 2.9 \cdot 10^{-11} \mu_B$ (90% CL). CEνNS has never been observed for the low-energy reactor neutrino. While observing, it opens a way to search for non-standard neutrino interaction and applied research, like reactor monitoring. The νGeN experimental setup is constructed under reactor #3 of KNPP at a distance of about 10 m from the center of the reactor's core under an enormous antineutrino flux of more than $5 \cdot 10^{13}$ neutrinos/cm^2/s. A special lifting mechanism allows moving the spectrometer away from the reactor core, suppressing main systematic errors caused by possible long-term instability and neutrino flux. Signals from neutrino scattering are detected with help of high purity low-threshold germanium detectors. New detectors in νGeN project with a resolution of about 80 eV (FWHM) with masses of more than 1 kg each are used to detect neutrino signals. It would allow exploring an energy region below 250 eV. Detectors at KNPP are surrounded by passive and active shielding reducing the external background in the region of interest. First coherent neutrino scattering from reactor would be observed in case of desired background level and energy resolution at KNPP are achieved. This setup would also open a way to investigate the coherent neutrino scattering with a much higher sensitivity to the non-standard neutrino interactions. The experimental sensitivity to NMM with νGeN will be improved to the level of ~ $(5\text{-}9) \cdot 10^{-12}$ μ_B after several years of data taking.

Supervisor's specific requirements:

- Candidates are expected to hold a master degree in particle or nuclear physics.
- Programming experience in C++ is required.
- The experience with data analysis and knowledge of ROOT is an advantage.

Possible theme for PhD thesis:

The theme of the PhD thesis will be devoted to investigation performed within the νGeN project. νGeN experiment recently started to take data with a first detector. The main aims of the current investigation will be data analysis and simulations. In addition, test measurements with new HPGe detectors, electronics and active shielding can be performed within the current research.

Main publications:

- V. Belov et al., "The νGeN experiment at the Kalinin Nuclear Power Plant", 2015 JINST 10 P12011.
- A. Beda et al. GEMMA experiment: the results of neutrino magnetic moment search, Physics of Particles and Nuclei Letters, 2013, V.10, №2, pp.139-143.
- https://indico.jinr.ru/event/1834/contributions/11511/attachments/9173/14534/03.4.%20vGeN%28GEMMA%29-Lubashevskiy_PAC2021.pdf
- https://indico.jinr.ru/event/1834/attachments/9164/14502/nuGeN-GEMMA_project_with_forms.pdf

Direct Dark Matter search and precision study of CEνNS with new cryogenic detectors

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Experiment. 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. Recent results demonstrated the high relevance of cryogenic Ge detectors for the search of DM interactions producing eV-scale signals [1]. The same technology and detectors will be applied for precision measurements of CEνNS in the region of full coherency in the **Ricochet** experiment (reactor neutrinos) [2,3]. Due to direct energy reconstruction (heat signal) the main uncertainty arising due to not well known quenching in germanium will be avoided. 1 kg of new cryogenic detectors (developing thanks to joint R&D of EDELWEISS and Ricochet teams) will be integrated in the Ricochet cryostat. The Ricochet is going to be deployed at ILL (Grenoble, France) site, on a distance at about 8 m from the 58 MW nuclear reactor, with first results expected to 2025. In addition to the main goal: precise (1% level) study of CEνNS the experiment will target NMM and other New physics phenomena.

Requirements for candidate: knowledge of nuclear physics, modern experimental techniques, program languages (C++, etc), root environment, etc.

Possible themes for PhD thesis:

- *Study of low energy background in the CEνNS – related experiments induced by high energy γ-rays produced after neutron's reactions in surrounding materials.* The aim is estimation of the background associated with reactions of ambient and reactor neutrons on materials of the Ricochet setup. Neutron capture is often followed by gamma rays with energies up to 10 MeV. Such energetic gammas have good penetration power and can pass inside of the shield. Their interaction with nuclear in the detectors could lead to different effects on 1-100 eV scale. Those effects are purely known. In the same time such effects have a crucial role for interpretation of CEνNS and Dark Matter – related experiments.
- *Estimation of fast neutron flux in the Ricochet experiment from their inelastic scattering off Ge.* The aim is independent estimation of the one of most important from backgrounds: fast neutrons. Recoils of fast neutrons in the detectors are undistinguishable from CEνNS events. One of the possibilities to get knowledge about the neutron background in the near zero energy range is to study high/middle energy events induced by inelastic neutrons scattering off Ge nuclear.

Publications & links:

1. EDELWEISS collaboration, Q Arnaud et al., First germanium-based constraints on subMeV Dark Matter with the EDELWEISS experiment, PRL 125, 141301 (2020) , arXiv:2003.01046, https://doi.org/10.1103/PhysRevLett.125.141301
2. https://indico.jinr.ru/event/1834/contributions/11512/attachments/9174/14535/03.5.%20EDELWEISS-RICOCHET-Yakushev-PAC2021.pdf
3. https://indico.jinr.ru/event/1834/attachments/9163/14495/EDELWEISS-RICOCHET_project_with_forms.pdf

SuperNEMO

Investigation of the 2β-decay processes of ^{82}Se with the SuperNEMO detector

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Experiment. The Experimental searches for neutrinoless double beta decay is one of the most active research areas in neutrino physics. Observation of such a process would provide such important information as proof of the Majorana nature of neutrino (neutrino is its own antiparticle) and can make it possible to determine the absolute neutrino mass scale.

The SuperNEMO project is aimed to search for neutrinoless double beta decay of ^{82}Se with a sensitivity to the decay half-life of the order of 10^{26} years, corresponding to a Majorana neutrino mass of 50-100 meV. The main advantage of the SuperNEMO project is a unique potentially zero background tracking-calorimetric technique, which allows the reconstruction of the event topology and of the full kinematics of detected particles, including individual energies and emission angles. This is important in order to unveil the mechanism responsible for the decay.

The SuperNEMO experimental setup has a modular structure. The first module (Demonstrator) is already installed in the Frejus underground laboratory (Modane, France) and will start data taking in 2021. It should demonstrate the efficiency of the developed tracko-calorimetric method and the possibility of fulfilling the requirements of the SuperNEMO experiment in terms of the background, energy resolution of the calorimeter, and, ultimately, sensitivity. The Demonstrator module by itself will have an important physics programme, including an expected 0νββ-decay half-life sensitivity $T_{1/2} > 6 \cdot 10^{24}$ years with 6.3 kg of ^{82}Se in 2.5 years of data taking as well as unique studies of the 2νββ decay mode.

The SuperNEMO is an international collaboration with about 100 participants from 7 countries. The JINR SuperNEMO team needs a PhD student to be occupied with the data analysis.

Requirements for candidate: Knowledge of C++ programming language and the ROOT software is necessary.

Possible themes for PhD thesis:

- *Measurement of background in the double beta decay experiment SuperNEMO.*
- *Investigation of the ββ-decay processes of ^{82}Se with the SuperNEMO detector.*

Publications & links:

- Main cite of the project https://supernemo.org
- SuperNEMO presentation @ conference https://indico.cern.ch/event/716539/contributions/3245944/
- Ph.D. thesis (**you will do the same!**) http://www.hep.ucl.ac.uk/theses/James_Mott_Thesis.pdf

Search for rare decays with the TGV/OBELIX spectrometers

Research supervisor:
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Experiments. TGV-2 is aimed to investigate of two-neutrino EC/EC decay of ^{106}Cd with a transition to the ground state of ^{106}Pd ($0^+ \rightarrow 0^+$, g.s.), which is characterized by emission of only two Palladium (Pd) X–rays each with an energy of ~ 21 keV. Direct observation of this rare process is possible only by detection of KX(Pd)-KX(Pd) from this decay. The TGV-2 spectrometer [1] using in this investigation consists of 32 planar type HPGe detectors with the sensitive volume of 2040 mm^2 x 6 mm each (about 3 kg of Ge). **The OBELIX** detector [2] is extra-large an extra radio-pure HPGE, which was produced by the Canberra and is based on P-type crystal with a sensitive volume of 600 cm^3. The mass of the detector is approximately 3.2 kg and the detector relative efficiency is 160%. The crystal was mounted in the ultra low background U-type cryostat. The energy resolution (FWHM) of the detector is ~1.2 keV at 122 keV (^{57}Co) and ~2 keV at 1332 keV (^{60}Co). Both spectrometers are located in the deep underground laboratory (LSM, Modane, France,4800 m w.e.) which allows us to suppress cosmic rays and fast neutrons.

Requirements for candidate: knowledge of nuclear physics, modern experimental techniques, root environment, etc.

Possible themes for PhD thesis:

TGV. *Investigation of 2νEC/EC capture of ^{106}Cd*. The main topics of the propose PhD project are: i) processing of experimental data obtained with the TGV-2 spectrometer during in approximately 7 years of measurement; ii) simulation of the geometry of TGV-2 experiment to obtain the efficiency of measurement; iii) analyzing KX(Pd)–KX(Pd) coincidences recorded in neighboring detectors to search for 2νEC/EC capture in ^{106}Cd decay.

OBELIX. *Investigation of 2νββ* decay of ^{82}Se *with the Obelix spectrometer*. The main topics of the propose PhD project are: i) processing of experimental data obtained with the OBELIX spectrometer during measurement of ^{82}Se; ii) simulation of the geometry of the experiment to obtain the efficiency of measurement.

Publications

1. P. Beneš et al., *Nucl. Instr. Meth. in Phys. Res.* A **569**, (2006) 737-742. https://doi.org/10.1134/S1063778806120167
2. V.B. Brudanin et al., *JINST*, 12, (2017), P02004, https://doi.org/10.1088/1748-0221/12/02/P02004.

Materials purification for low-background researches

Research supervisor:
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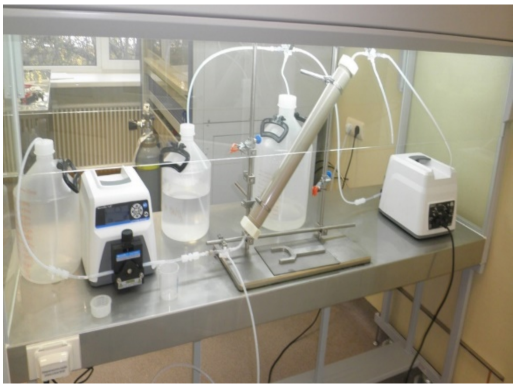
Experiment. The study on neutrino properties plays an important role in particle physics. The only practical way to prove of neutrino Majorana nature and lepton number violation is the establishment of neutrinoless double-beta decay (0νββ). For this purpose, number of experiments, eg. AMoRE-I, CUORE, CUORICINO+, CUPID-0, GERDA, EXO-200, Kamland-Zen, MAJORANO, NEMO-3/SuperNEMO, SNO+ are used [1-3]. ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{130}Te, ^{136}Xe, ^{150}Nd enriched isotopes after a high purification are candidates for 0νββ decay search. 2.5 kg of enriched ^{82}Se were purified in our radiochemistry department for the SuperNEMO experiment. To purify of ^{82}Se from radioactive impurities of potassium (^{40}K), radium (^{226}Ra), actinium (^{227}Ac), thorium (^{232}Th) and uranium (^{238}U), new and unique methods of purification were developed, reaching a level of radioactive impurities of the order of μBq / kg. The sample contaminations were analyzed with at a similar sensitivity level. The conducted radioanalytical measurements have confirmed the high quality of purified ^{82}Se and low content of radioactive impurities.

Requirements for candidate: knowledge of analytical chemistry, radiochemistry, chromatography, nuclear physics etc.

Possible themes for PhD thesis:



- *Development of new purification methods of Nd from radioactive impurities.* Due to high decay energy of ^{150}Nd (3367 keV) are perspective candidate for 0νββ decay research. The main chemical problem of Nd purification is the removal of rare earth elements and actinium. To obtain of high quality Nd, new and unique methods should be developed.
- *Radiochemical aspects of Zr production for rare process search.* Due to high decay energy of ^{96}Zr (3350 keV) are perspective candidate for 0νββ decay research. The key point of Zr purification is transfer of oxide form to solution and back to solid phase, as well as separation from radionuclides with similar properties (thorium and uranium).

Nowadays enriched ^{96}Zr and ^{150}Nd were not obtained in significant amount. As the result the purification methods of macro amounts were not developed yet.

Publications & links:

4. Barabash A.S. Possibilities of future double beta decay experiments to investigate inverted and normal ordering region of neutrino mass. Frontiers in Physics. V 6, 160 (2019). https://doi.org/10.3389/fphy.2018.00160.
5. Arnold, R., Augier, C., Barabash, A.S. et al. Final results on ^{82}Se double beta decay to the ground state of ^{82}Kr from the NEMO-3 experiment. Eur. Phys. J. C 78, 821 (2018). https://doi.org/10.1140/epjc/s10052-018-6295-x.
6. Arnold, R., Augier, C., Barabash, A.S. et al. Search for the double-beta decay of ^{82}Se to the excited states of ^{82}Kr with NEMO-3. Nuc. Phys A, V 996, 121701 (2020). https://doi.org/10.1016/j.nuclphysa.2020.121701.

BAIKAL-GVD

Deep underwater muon and neutrino detector on Lake Baikal

Experiment. The construction of the Baikal-GVD neutrino telescope [1] is motivated by its discovery potential in astrophysics, cosmology and particle physics. Its primary goal is the detailed study the diffuse flux of high-energy cosmic neutrinos and the search for their sources. It will also search for dark matter candidates (WIMPs), for neutrinos from the decay of super heavy particles, for magnetic monopoles and other exotic particles. The high angular resolution of the detector for track-like or cascade-like events (~0.25-0.5° for muon tracks and ~2-3° for cascades, respectively) provides a high capability for identifying point-like cosmic-ray accelerators. It will also be a platform for environmental studies in Lake Baikal.

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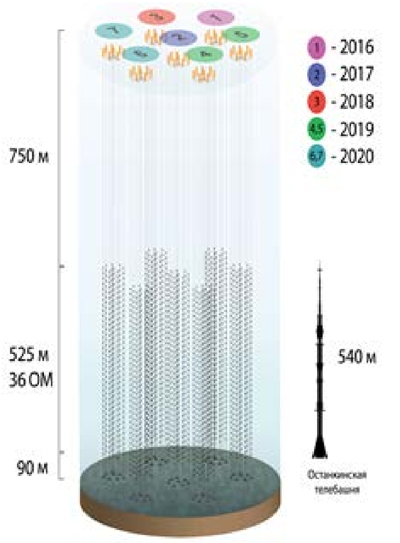
Now (2021), the detector has 8 clusters spaced on 300 m apart to each other and has effective volume for high energy cascade events about 0.4 $км^3$.

Oopportunities for PhD thesis: any of following subjects leading by JINR group:

- Assembly and test of OMs and strings
- Participation in winter deployment campaigns
- Access and security service
- Data archive processing and analysis
- Detector calibration and mass processing of data
- Remote control and monitoring systems of detector
- Simulation software and MK production
- On-line software
- Development of new methods of event selection and reconstruction.
- Data analysis with respect to high-energy neutrinos and neutrinos from dark matter.



General requirements for candidate: excellent knowledge of nuclear and particle physics, modern experimental techniques, analysis and modeling environments (root, geant, etc). **Good physical shape is necessary to participate in expeditions to Lake Baikal!**

Publications & links:

1. https://baikalgvd.jinr.ru/