GERDA project

1. Goals of the experiment:

1a. Give a short description of the goals of the experiment - limited to ½ page.

The GERDA experiment is designed to search for neutrinoless double beta ($0\nu\beta\beta$) decay of ^{76}Ge. GERDA operates with bare germanium detectors (enriched in ^{76}Ge) directly immersed in liquid argon (LAr). After the successful completion of the first phase of the experiment the second phase of GERDA has been started. In GERDA Phase II detector mass is doubled by adding novel germanium detectors with improved energy resolution and pulse shape discrimination capability. Moreover, in Phase II the LAr is instrumented to readout liquid argon scintillations for vetoing background events. As the result, the background level is reduced down to the unprecedented value of 10^{-3} counts keV^{-1} kg^{-1} yr^{-1}. Thus an average background less than one count expected in the ROI up to the design exposure of 100 kg yr. This implies that GERDA is the first background-free $0\nu\beta\beta$ experiment. GERDA will continue data taking until the designed exposure of 100 kg yr is achieved, which is planned for 2019. Then the half-life sensitivity will be above $1.4 \cdot 10^{26}$ yr.

Building on the experience with the background reduction technique developed by GERDA, the next generation project LEGEND will be 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 detectors at the background level of ~ 0.6 counts FWHM^{-1} t^{-1} yr^{-1} and to reach the sensitivity of 10^{27} years. The second phase is designing to work with up to 1000 kg at ~ 0.1 counts FWHM^{-1} t^{-1} yr^{-1} and to achieve 10^{28} years. Therefore, the background should be reduced further by 5 and 30 times respectively compared with GERDA. The ultimate goal of the new project is to explore the full neutrino mass range predicted for the inverted mass hierarchy.

1b. Explain what the project adds to the international scenario: limited to ½ page.

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 neutrinoless double beta decay. Moreover, this process violates lepton number conservation. Hence, it is forbidden within the Standard Model (SM) of particle physics. Therefore, the discovery of $0\nu\beta\beta$ decay will confirm the existence of New Physics beyond SM. That is the reason why during decades, this search remains worldwide ranked amongst the top research priorities.

In order to complete the investigation of the neutrino mass interval predicted by neutrino oscillation experiments for the inverse mass ordering, it is necessary to operate with ton of detector mass at zero background. Several projects aimed to fulfill these requirements. However, given the high costs for isotopic enrichment of neutrinoless double beta decay isotopes, it is unlikely that more than three ton scale experiments will be realized worldwide. A down selection based on proven experimental performances will be carried out by coordinating committees and funding agencies during the next few years.

The experimental signature for discovery of $0\nu\beta\beta$ 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 best $0\nu\beta\beta$ discovery potential to an ultra-low background germanium-based experiment amongst all competitors due to the excellent resolution of Ge detectors. Nevertheless, the possible discovery has to be proven with multiple isotopes using different experimental methods. As it has been recently estimated the discovery probability of next generation of double beta decay experiments is significant even in the case of normal ordering.

2. Contributions of the JINR group:

2a. Give an itemized list of the specific contributions of the JINR group in hardware (including use of JINR computing resources for the project), software development and physics analyses - limited to 1 page.

- Plastic muon veto that is being used in all phases of the GERDA experiment and planned to be used in the LEGEND-200 has been produced, installed and supplied by JINR group.
- Improved version of liquid argon veto and the central fiber module, which have been added in GERDA during the upgrade of the experiment in May-July of 2018, have been developed, produced, tested and installed by common JINR and TUM team.
- The principles of using liquid argon as an active veto have been developed and tested by using the LArGe test facility, which was constructed and operated by JINR and MPIK group. It worth to mention, that mainly JINR members have performed the data analysis for LArGe.
- A special tool for suppression of dominant ^{42}Ar background for GERDA Phase II (nylon mini-shrouds covered by wavelength shifter) has been developed, produced, tested and installed by JINR people. It helped to reach the desired background level and to improve the performance of LAr veto.
- JINR members played the important role in the development of methods of pulse shape discrimination for novel germanium detectors used in GERDA Phase II.
- JINR people were responsible to test, mount, integrate and commission the core of the GERDA experiment – detector arrays in both phases of the project.
- JINR is providing ~ 8 kg of enriched ^{76}Ge for the GERDA and LEGEND projects.
- The JINR group played the core and leading role in the preparation, organization and realization of the upgrade of GERDA Phase II performed in 2018.

2b. Give a list of the responsibilities of JINR group members within the management structure of the collaboration, if any, giving the name of the JINR member, the managerial role and the appointment period.

K. Gusev is permanent member of the GERDA Collaboration Board.

K. Gusev is Technical Coordinator of the GERDA experiment and head of the Integration Task Group.

A. Lubashevskiy is member of GERDA Speakers Bureau.

A. Smolnikov is member of GERDA Editorial Board and co-head of the LArGe Task Group.

3. Plans

Give a short description limited to ½ page of the JINR group plans (in data taking, analysis, detector R&D, upgrade activities…) till the end of the currently approved project.

The GERDA experiment is going to reach the designed exposure in the end of 2019. Then the existing GERDA infrastructure will be modified to adopt up to 200 kg of Ge detectors in the first phase of LEGEND project. The actual plan is to start the data taking in LEGEND-200 in 2021. The JINR group will participate in all stages of GERDA and LEGEND experiment.

- JINR specialists will keep participating in the GERDA data analysis until the final release of data and in the simulation work for the LEGEND project.
- Thanks to the invaluable experience of the JINR group in the operations with Ge detectors, we are going to keep the leading role in this activity in both experiments.
    - JINR specialists will be strongly involved in the GERDA detector array dismounting procedure. This work is planned to be organized by JINR people.
    - The JINR group is going to participate in the procurement, testing and installation of new enriched Ge detectors for LEGEND-200.
- JINR people are joining the R&D and realization of new active liquid argon veto system for LEGEND experiment.
- The JINR team will dismount and mount back the plastic muon veto system during the transition phase from GERDA to LEGEND.
- JINR group in LEGEND-200 will be partly or fully responsible for:
    - The R&D and production of nylon mini-shrouds (tool needed for suppression of dominant ^{42}Ar background);
    - The design and procurement of the new glove box for the operation with enriched Ge detectors;
    - The design of the detector holders and strings. We plan to use for 3D printing machines at JINR to produce some parts of a detector holder. That opens very fast and effective way to find all possible design flaws and probably to produce ultra-clean holders.
- Now we are designing and procuring **the test facility at JINR** in the recently made clean room for Ge detector testing and nylon mini-shroud production and testing**.** This facility will include:
    - The wide neck cryostat connected to the nitrogen-flushed glove box to perform all detector and mini-shroud handling in the ultra-clean environment;
    - The stand for nylon mini-shroud production;
    - The deep access bonding machine to provide good quality and low mass contacts to Ge detectors;
    - Few natural germanium detectors of the same types as they are going to be used in LEGEND-200.

4. Publications:

List the papers published in 2016, 2017 and 2018 in the refereed literature (no conference proceedings) in which the JINR group had a major contribution (e.g. author of the analysis, promoter of the experiment, corresponding author, realization of a key equipment etc.). Give title of paper, reference and describe in 1-2 sentences the JINR contribution. Mention the total number of papers published by the project in the same time period.

Since the GERDA collaboration has only about 100 members, every GERDA publication is the common work of all people involved in the experiment.

1. «Improved Limit on Neutrinoless Double-β Decay of ^{76}Ge from GERDA Phase II», PRL 120 (2018) 132503.
2. «Upgrade for Phase II of the GERDA Experiment», EPJC 78 (2018) 388.
3. «Mitigation of ^{42}Ar/^{42}K background for the GERDA Phase II experiment», EPJC (2018) 78:15 (corresponding author: A. Lubashevskiy).
4. «Background-free search for neutrinoless double-β decay of ^{76}Ge with GERDA», Nature 544 (2017) 47.
5. «Limits on uranium and thorium bulk content in GERDA Phase I detectors», Astrop. Phys. 91 (2017) 15.
6. «Flux modulations seen by the muon veto of the GERDA experiment», Astrop. Phys. 84 (2016) 29.
7. «Limit on the radiative neutrinoless double electron capture of ^{36}Ar from GERDA Phase I», EPJC 76 (2016) 652.

8. «The performance of the Muon Veto of the GERDA experiment», EPJC 76 (2016) 298.

5. PhD theses:

List the PhD theses completed within the last 3 years, or expected to be completed within 2019, by JINR students within the project, giving the student name, thesis title and graduation year.

N. Rumyantseva, PhD thesis in preparation, preliminary title: «Investigation of germanium detectors and background reduction methods in the double beta decay experiments with ^{76}Ge», expected to be completed in 2019.

D. Zinatulina, PhD thesis in preparation, preliminary title: «Measurement of total and partial muon capture rates and the yields of the products in ($\mu-$, νXn) reaction in ^{48}Ti, ^{76}Se, ^{82}Kr and ^{150}Sm for nuclear matrix elements calculation in 2β-decays», expected to be completed in 2019.

6. Talks:

6a. List the invited plenary talks given by members of the JINR group in 2016, 2017 and 2018 at international conferences, workshops…: give name and date of the Conference, title of talk and speaker name.

- Neutrino Oscillation Workshop 2018, 9-16 September 2018, «Neutrinoless double beta decay: Experimental challenges», K. Gusev
- 6th International Conference on New Frontiers in Physics (ICNFP 2017), 17-29 August 2017, «GERDA: first background free search for neutrinoless double beta decay», K. Gusev
- 22nd International Symposium on Particles, Strings and Cosmology, XIIth Rencontres du Vietnam, 10-16 July 2016, «Neutrinoless double beta decay: First results of GERDA Phase II and the status of other experiments», A. Lubashevskiy
- International Session-Conference of the Section of Nuclear Physics of PSD RAS, 12-15 April 2016, «Double Beta Decay Experiments», K. Gusev

6b. Give a similar list for parallel talks.

- Nucleus-2018, 1-6 July 2018, «New types of germanium detectors to search for a neutrinoless double beta decay», N. Rumyantseva
- Nucleus-2018, 1-6 July 2018, «New results of the search for neutrinoless double beta decay from GERDA Phase II», N. Rumyantseva
- 7th Conference of Young Scientists and Specialists of JINR Alushta-2018, 11-18 June 2018, «Active liquid argon veto for GERDA Phase II», E. Shevchik
- 6th International Conference on New Frontiers in Physics (ICNFP 2017), 17-29 August 2017, «LEGEND: new opportunity to discover the neutrinoless double beta decay», K. Gusev
- International Session-Conference of the Section of Nuclear Physics of PSD RAS, 6-8 June 2017, «Neutrinoless double beta decay search with the «background free» GERDA experiment», A. Lubashevskiy
- International Session-Conference of the Section of Nuclear Physics of PSD RAS, 6-8 June 2017, « From Baksan to worldwide experiments searching for neutrinoless double beta decay», A. Smolnikov

- 19th International Seminar on High Energy Physics, Pushkin, Russia, 29 May - 4 June 2016, «Double beta decay experiments and neutrino mass investigation: Past, Present and Future», A. Smolnikov
- 26th International Nuclear Physics Conference (INPC2016), 11-16 September 2016, «First results from Phase II of the GERDA experiment», K. Gusev

7. Group size, composition and budget.

7a. Present in a Table the list of JINR personnel involved in the project, including name, status (e.g. PI, researcher, post-doc, student, engineer, technician…) and FTE. Mention the total number of people in the collaboration.

GERDA is an international collaboration that includes about 100 scientists from Italy, Germany, Russia, Poland, Switzerland, Belgium and JINR.

Name	Category	Responsibilities	Time that each participant will give to the work under the Project in relation to its Full Time Equivalent(FTE)
V. Brudanin	Head of department	Administrative work	0.1
D.Borowicz	Researcher	Ge detectors	0.8
K.Gusev	Senior researcher	Project Leader (technical coordination of the GERDA experiment, project coordination at JINR, Ge detectors)	1.0
V.Egorov	Senior researcher	Active veto system	0.1
M.Fomina	Junior researcher	Active veto system	0.2
A.Klimenko	Senior researcher	Analysis	0.5
O.Kochetov	Senior researcher	Ultrapure materials, active veto systems	0.1
A.Lubashevskiy	Senior researcher	Project Deputy Leader (analysis coordination, ultrapure materials, Ge detectors)	0.4
I.Nemchenok	Head of group	Ultrapure materials, active veto systems	0.2
S.Nepochatich	Junior researcher	Ge detectors, analysis	1.0
N.Rumyantseva	Junior researcher	Ge detectors, analysis	0.7
V.Sandukovsky	Head of sector	Ge detectors	0.5
E.Shevchik	Engineer	Active veto systems	0.2
M.Shirchenko	Researcher	Active veto systems, Ge detectors	0.3
A.Smolnikov	Senior researcher	Active veto systems, ultrapure materials, analysis	0.8
I.Zhitnikov	Junior researcher	Active veto systems, Ge detectors	0.2
D.Zinatulina	Researcher	Project Deputy Leader (muon veto coordination, Ge detectors)	0.4
Total FTE: 7.5			

7b. Indicate the expected changes in the group size, if any, till the end of the currently approved project.

Since the LEGEND collaboration includes many more people than GERDA the increase of the JINR team is expected maybe even within the next few years. We are willing to enlarge especially the analysis part of our group.

7c. Present the JINR group budget from 2018 till the end of the currently approved project in a Table specifying the main budget items (equipment, computing, salaries, common funds, travel…)

The GERDA project is part of the scientific theme 1100 "Non-accelerator neutrino physics and astrophysics" at JINR which is devoted to search and investigation of rear processes by means of nuclear physics methods. Implementation of projects conducted under the theme relates to common approaches and resources. In addition to five scientific sectors involved in the theme, 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 radioactivity, etc.), mechanical workshops, a group of computer support, a group of mass separators and others.

GERDA-only requested resources are reflected into the forms No.26 and No.29 of the written project (PAC-NP, January 2018) - duplicated on the next pages.

Form No. 26

Schedule proposal and resources required for the implementation of the Project GERDA ("G&M")

Expenditures, resources, financing sources			Costs (k$) Resource requirements	Proposals of the Laboratory on the distribution of finances and resources		
				1[st] year	2[nd] year	3[rd] year
Expenditures		1. Production of the test stand for Ge detectors	40	30	10	
		2. R&D of ultrapure materials	30	10	10	10
		3. Procurement of ^{76}Ge detectors	150	50	50	50
		4. R&D of low background electronics	30	10	10	10
		5. R&D of active veto systems	30	10	10	10
		6. Procurement of prototype detectors	60	60		
		Construction/repair of premises				
		Materials:				
		1. Enriched ^{76}Ge	150	50	50	50
		2. Scintillating materials	30	20	7	3
		3. Chemicals for Ge detectors	5	2	2	1
Required resources	Standard hour	Resources of – Laboratory design bureau; – JINR Experimental Workshop; – Laboratory experimental facilities division; – accelerator; – computer. Operating costs.				
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources.	621	274	181	166
	External resources	Contributions by collaborators. Grants. Contributions by sponsors. Contracts. Other financial resources, etc.	30	10	10	10

Estimated expenditures for the Project GERDA ("G&M"): searching for neutrinoless double beta decay of Ge-76

	Expenditure items	Full cost	1st year	2nd year	3rd year
	Direct expenses for the Project				
1.	Accelerator, reactor	h			
2.	Computers	h			
3.	Computer connection	6 k$	2	2	2
4.	Design bureau	standard hour			
5.	Experimental Workshop	standard hour			
6.	Materials	185 k$	72	59	54
7.	Equipment	340 k$	170	90	80
8.	Construction/repair of premises	k$			
9.	Payments for agreement-based research	k$			
10.	Travel allowance, including:	90 k$	30	30	30
	a) non-rouble zone countries				
	b) rouble zone countries				
	c) protocol-based				
	Total direct expenses	**621**	**274**	**181**	**166**

7d. Indicate the use of JINR computing resources for the group and for the project if any.

N/A