Annotation of the project
GERDA (“G&M”):
Searching for neutrinoless double beta decay of ^{76}Ge

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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 (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 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.

The GERDA collaboration searches for 0νββ decay of ^{76}Ge. The experimental facility is located at the Laboratori Nazionali del Gran Sasso of INFN in Italy. GERDA uses high purity germanium detectors enriched in ^{76}Ge, which are arranged in strings inside a cryostat filled with 64 m^3 of liquid argon (Fig. 1a). The liquid argon (LAr) acts both as cooling and shielding medium. GERDA has been proceeded in two phases.

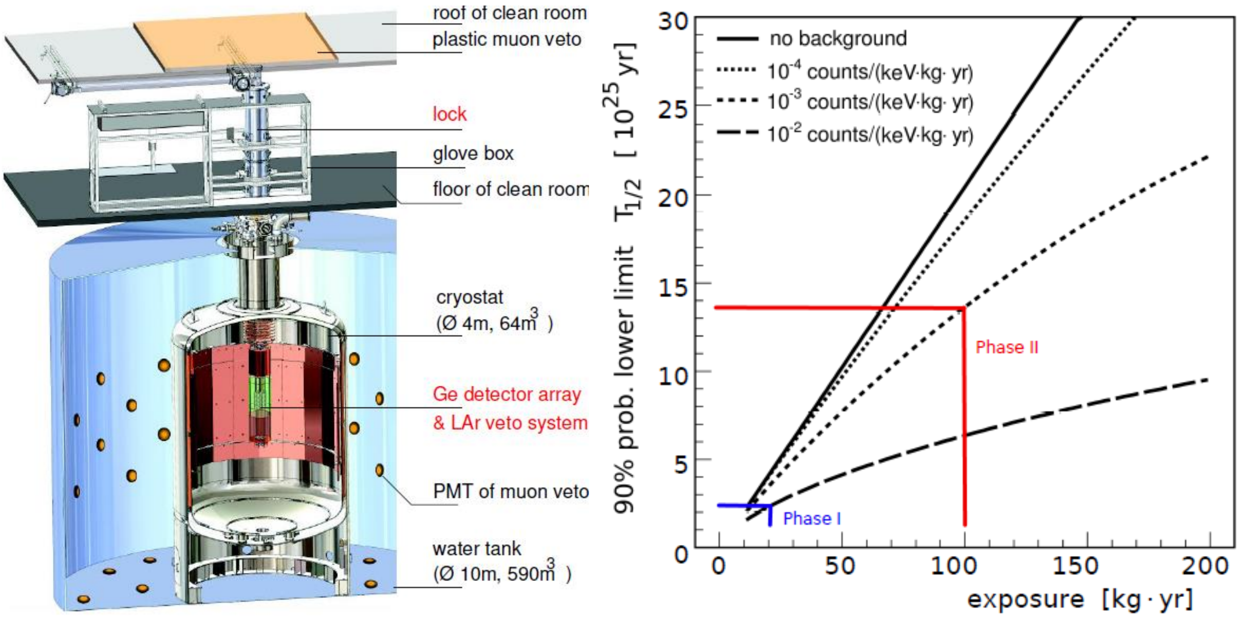

Fig 1. a) Left: GERDA setup. The new Phase II components are marked in red; b) right: estimated sensitivity of the GERDA experiment as a function of exposure for various background indices. The scenarios for GERDA Phase I and II are indicated.

The physics results of Phase I [1, 2] were based on an exposure of 21.6 kg yr. A background index (BI) of about 10^{-2} counts keV^{-1} kg^{-1} yr^{-1} was achieved, one order of magnitude lower than in the best previous 0νββ decay experiments. No signal was found for 0νββ decay, and a new 90% confidence level (CL) limit of $T_{1/2}^{0\nu}$ > 2.1 × 10^{25} years was derived (median sensitivity 2.4 × 10^{25} years) that strongly disfavored a previous claim of observation. Further Phase I results include an significantly improved half-life for 2νββ decay of ^{76}Ge and improved limits for Majoron decay modes [3], as well as 2νββ decays of ^{76}Ge into excited states of ^{76}Se [4].

Phase II of GERDA was aimed to improve the sensitivity on the half-life of 0νββ decay by about one order of magnitude. The half-life sensitivity of 0νββ experiments grows linearly with the exposure, as long as there are no background counts in the ROI close to decay energy. GERDA Phase II is the first background free search for 0νββ decay because of achieved unique background level of 10^{-3} counts keV^{-1} kg^{-1} yr^{-1}. This will allow Phase II to reach the expected sensitivity more 10^{26} years at an exposure of about 100 kg yr (Fig. 1b).

The most important feature of Phase II is the LAr instrumentation surrounding the detector array to readout of scintillation light creating an effective active LAr veto system. It was developed from studies of scintillation light detection in LAr in the low-background test facility LArGe [5] and silicon photomultipliers (SiPMs) coupled to wavelength shifting fibers for increasing light detection efficiency. The usefulness of this approach has been fully proven by the first results obtained with the upgraded GERDA experiment. Started in December 2015, the Phase II physics run reached in June 2016 the exposure of 10.8 kg yr. These accumulated data have been already sufficient to ensure that the projected background level of 10^{-3} counts keV^{-1} kg^{-1} yr^{-1} has been achieved and, to set in combination with the Phase I data a new lower limit for the 0νββ decay half-life of ^{76}Ge of > 5.3 x 10^{25} years at 90% CL [6].

Latest results:

The energy spectrum of Phase II exposure of BEGe detectors collected so far is presented at Fig. 2. The blinded region around the $Q_{\beta\beta}$ is marked by the vertical band. Up to 500 keV the spectrum is mainly consists of ^{39}Ar events, up to 1.8 MeV by events from 2νββ decays of ^{76}Ge and Compton scattered events – mostly from the ^{40}K and ^{42}K γ lines. For the energies higher than 2.62 MeV the events come from α decays at the p^{+} electrode or at the detector groove – generally from ^{210}Po. The origin of the ^{40}K γ line is an electron capture therefore no energy left in the LAr and only PSD is effective to cut these events. The ^{42}K γ line comes from a β decay and up to 2 MeV are deposited in argon that allows the LAr veto to reject more than 80% of such events. At $Q_{\beta\beta}$ the spectrum consists of degraded α, ^{42}K decays at the detector surface and Compton scattered γ's from ^{214}Bi and ^{208}Tl decays. The background index for BEGe detectors is equal to $1.0^{+0.6}_{-0.4} \times 10^{-3}$ counts keV^{-1} kg^{-1} yr^{-1}. If normalized to the energy resolution and signal efficiency this value is more than factor of five lower compared with any non-^{76}Ge competitors.

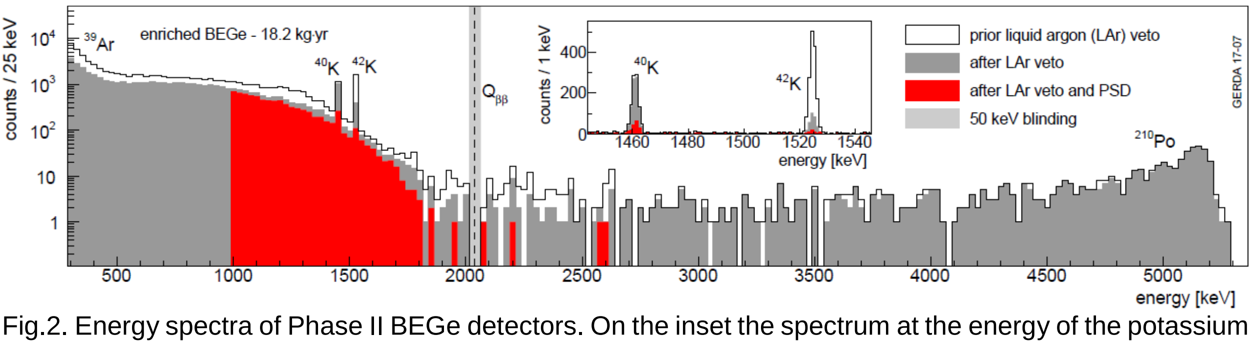

Fig.2. Energy spectra of Phase II BEGe detectors. On the inset the spectrum at the energy of the potassium lines is shown. The vertical grey line band shows the blinded region.

The total exposure used for the last analysis is 23.5 kg yr and 23.2 kg yr for Phase I and Phase II, respectively. No event close to $Q_{\beta\beta}$ has been found and a 90% C.L. lower limit of $T_{1/2}^{0\nu} > 8.0 \times 10^{25}$ years has been set for a frequentist analysis, with a median sensitivity of 5.8×10^{25} years. This is the best half-life sensitivity amongst all existing 0νββ experiments.

GERDA data taking is ongoing until the designed exposure of 100 kg yr will be achieved. It is planned to be reached in 2019-2020. Then the half-life sensitivity will be well above 1.0×10^{26} years. The sensitivity of GERDA can be additionally improved by reducing the background of the experiment and adding of novel enriched Ge detectors. Such an upgrade of GERDA is going to be performed in 2018-2019. It should include not only the increase of enriched isotope mass by adding of new enriched detectors but also the replacement of existing active liquid argon veto by improved version.

The GERDA experiment design sensitivity will not allow to get an information about neutrino mass hierarchy. In order to address this issue the new generation experiment LEGEND is being built. It is foreseen at least two phases of the project. The first phase will operate with ~ 200 kg of enriched isotope and the expected sensitivity will be 10^{27} years. The second phase will use 1000 kg and reach 10^{28} years respectively. This project will allow answering 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. The first phase of new experiment is going to use the existing GERDA infrastructure at LNGS. Our goal is to start data taking in the first phase of LEGEND in 2021.

The GERDA collaboration consists of more than 100 physicists from 16 institutions of six countries. JINR scientists are playing significant roles in all key parts of the project. DLNP JINR was responsible for design, production, testing and installation of plastic muon veto system. JINR specialists actively participated in the development of LAr instrumentation. Physicists from our institute are strongly involved in the analysis of GERDA data and play the central and leading roles in the core of GERDA experiment – operations with bare germanium detectors. Scientists from JINR plan to actively participate or even take the lead in the key parts of the new generation project LEGEND.

Plan of the Project implementation:

2018-2019: The upgrade of the GERDA experiment by adding novel enriched detectors and exchanging of the existing liquid argon veto by improved version. Achieving of design sensitivity of 10^{26} years.

2019-2020: Reaching of planned GERDA exposure of 100 kg yr. Preparation of the first phase of next generation experiment LEGEND (procurement of enriched ^{76}Ge, production and testing of new Ge detectors, R&D of low background materials and electronics).

2020-2021: Completion of the GERDA experiment, publication of results. Modification of GERDA cryostat for LEGEND Phase I. Integration and start data taking of the LEGEND experiment.

References

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