Besides photons neutrinos are the most abundant particles in the Universe. They are often called `ghost particles', because they interact extremely weakly with matter. They are therefore an invisible, but very important component of the Universe and could carry as much mass as all other known forms of matter put together − albeit traveling at almost the speed of light over vast distances. Their tiny mass also has important consequences for the structures in the Universe and they are a driving element in the explosion of Supernovae. Yet their most remarkable and important property was proposed by Ettore Majorana in the 1930s: Unlike all other particles that form known matter around us, neutrinos may be their own antiparticles.

The GERDA (GERmanium Detector Array) experiment, which is operated at the Laboratori Nazionali del Gran Sasso underground laboratory of the Istituto Nazionale di Fisica Nucleare in Italy, is aiming to resolve the question whether neutrinos are in fact their own antiparticles, and to determine their mass. GERDA looks for so-called double beta decay processes in the germanium isotope ^{76}Ge with and without the emission of neutrinos, the latter being a consequence of the Majorana properties. In normal beta decay, a neutron inside a nucleus decays to a proton, an electron and an antineutrino. For nuclei like ^{76}Ge, normal beta decay is energetically forbidden, but the simultaneous conversion of two neutrons with the emission of two neutrinos is possible and has been measured recently by GERDA with unprecedented precision. This is one of the rarest decays ever observed with a half-life of about $2 \cdot 10^{21}$ years − about 100 billion times the age of the Universe. If neutrinos are Majorana particles, neutrino-less double beta decay should also occur at an even lower rate. This is possible if neutrinos are their own antiparticle. Searching for a needle in a haystack is trivial compared to the detection of double beta decay, since environmental radioactivity is a background occurring at a rate at least a billion times higher than double beta decay. The GERDA detector crystals and the surrounding detector parts were therefore very carefully chosen and processed. The observation of this extremely rare process requires, in addition, very delicate techniques to further suppress backgrounds from cosmic particles, natural radioactivity of the surroundings and even the experiment itself. The scientists met this challenge by mounting the detectors in the center of a huge vessel filled with extremely clean liquid argon, lined by ultrapure copper. This in turn was surrounded by a 10-meter-diameter tank filled with pure water; the whole located underground below 1400 meters of rock. Combining all these innovative and pioneering techniques it was possible to reduce the background to unprecedented levels. The analysis, in which all calibrations and cuts had been defined before the data in the signal region was processed, revealed no signal of neutrino-less double beta decay in ^{76}Ge,leading to the world's best lower limit − a half-life of $2.1 \cdot 10^{25}$ years.

Recently the experiment has been upgraded to its Phase II (it is taking data since December 2015). The main goal of the upgrade was to double the mass of the applied germanium with simultaneous reduction of the signal from the residual natural radioactivity. Thanks to this we will have possibility to probe the half-life of ^{76}Ge up to 10^{26} years. Under preparation is also a world-wide cooperation with scientists carrying similar research in the frame of the NGe (Next Generation Germanium) experiment. The common effort with about 1 ton of ^{76}Ge would make it possible to investigate ^{76}Ge half-life up to 10^{27} years.

The already achieved and expected new results from GERDA have interesting consequences for knowledge on neutrino masses, extensions of the standard model of elementary particle physics, astrophysical processes and cosmology.

Tasks included in the presented project are focused on significant improvement of the sensitivity for observation of the neutrino-less double beta decay, which is the main goal of the GERDA and NGe experiments. It will be achieved by development and implementation of novel background reduction techniques.

GERDA is a European collaboration with scientists from 16 research institutes or universities in Germany, Italy, Russia, Switzerland, Poland and Belgium. The participating institutes are the Max-Planck-Institute for Nuclear Physics in Heidelberg, the Max-Planck-Institute for Physics and the Technical University in Munich, the universities of Tübingen and Dresden, INFN LNGS at Gran Sasso, INFN Milano, INFN Milano Bicocca, INFN Padova, INR, ITEP and Kurchatov Institute in Moscow, JINR Dubna, the universities of Zürich and Krakow and IRMM Geel.