Development and installation of the **GERDA** experiment

**GERDA**: the **GERmanium Detector Array**
to search for Neutrinoless Double Beta Decay

A.Smolnikov
for the GERDA collaboration

The 11-th International Conference on Topics in Astroparticle and Underground Physics, TAUP2009, Rome, Italy, July 1-5, 2009
The GERDA project is based on using very low background High-Purity-Germanium (HPGe) detectors.

HPGe detector fabricated from germanium enriched in $^{76}\text{Ge}$ isotope (up to 86 %) is simultaneously the \( \beta \beta \) decay source and the 4\( \pi \) detector.

**The advantages** of such type experiments (in comparison with the other types) are due to:

1) the excellent energy resolution (3 keV at 2 MeV),
2) the high purity of Ge crystals (very low intrinsic background),
3) and the high signal detection efficiency (close to 100%).

**Disadvantages:**

1) not the highest \( \beta \beta \)-transition energy for $^{76}\text{Ge}$: \( Q_{\beta \beta} = 2039 \) keV (in comparison with the more promising isotopes, such as Mo-100, Nd-150, Ca-48).

2) only one characteristic of \( \beta \beta \) decay - sum energy of two electrons – is possible to detect.

*In spite of these disadvantages, up to now such type of experiments are the most sensitive tools in searching for (0v\( \beta \beta \))-decay.*
Moreover, the part of H-M Collaboration, after additional data treatment, claimed the presence of an excess of events in ROI, which they interpreted as the evidence for $0\nu\beta\beta$ observation with the best fit $T_{1/2} = 1.2 \times 10^{25}$ y, $|m_{ee}| = 0.44$ eV.


The main goal of the GERDA experiment is searching for neutrinoless double beta decay of $^{76}\text{Ge}$ with considerable reduction of background (and, correspondently, increasing sensitivity) in comparison with predecessor experiments.
Expected sensitivity of the GERDA experiment

GERDA
will probe **Majorana nature of neutrino**
with sensitivity at

**GERDA phase I:**
with background $0.01 \text{ cts} / (\text{kg} \cdot \text{keV} \cdot \text{y})$
► to scrutinize KKDC result within 1 year

**GERDA phase II:**
with background $1 \text{ cts} / (\text{ton} \cdot \text{keV} \cdot \text{y})$
► to cover the degenerate neutrino mass hierarchy ($<m_{ee}> < 0.08 - 0.29 \text{ eV}$)

**phase III:**
world wide GERDA–MAJORANA collaboration
background $0.1 \text{ cts} / (\text{ton} \cdot \text{keV} \cdot \text{y})$
► to cover the inverted neutrino mass hierarchy

$m_{ee} \sim 10 \text{ meV}$
To achieve the planned sensitivity it is necessary to reduce the previous background level dramatically (several orders of magnitude!).

To do this the novel experimental concepts are needed.

**Main GERDA experimental concepts**

The main conceptual design of the GERDA experiment is to operate with “naked” HPGe detectors (enriched in Ge-76) submerged in high purity liquid argon supplemented by a water shield.

“Naked” detector means the bare Ge crystal without traditional vacuum cryostat.
As it was shown in the IGEX and H-M experiments, the main part of the detector background is due to radioactive contamination in the surrounding materials, including the copper cryostats.

Thus, **minimizing of the support material** mass in the case of using “naked” Ge detectors **should provide considerable (up to 100) reduction of the inner background**.

**Using of ultra pure LAr** (instead of LN) both **as a cooling media and shielding material** is the other perspective idea of the GERDA project.

In this case there are several advantages:

1) **the higher reduction factor of the external background due to higher LAr density (1.4 g/cm³)**;
2) **anti-coincidence with LAr scintillation** should reduce both the inner and external background;
In the Phase I all 8 existing and reprocessed enriched detectors (in total 18 kg of $^{76}\text{Ge}$) from the previous Heidelberg-Moscow and IGEX experiments, and 6 reprocessed natural HPGe detectors (in total 15 kg of $^{\text{Nat}}\text{Ge}$) from the Genius Test-Facility will be deployed in strings.

In the Phase II the new segmented or BeGe detectors (>20kg of $^{76}\text{Ge}$) made from recently produced enriched in $^{76}\text{Ge}$ material added. In total: 40 kg of $^{76}\text{Ge}$ + 15 kg of $^{\text{Nat}}\text{Ge}$.

In addition several detectors from depleted in $^{76}\text{Ge}$ material (DepGe ) will be incorporated too.

A stainless steel cryostat (25 t, U/Th ≤ 5 mBq/kg) with internal Cu shield (20 t, U/Th ≤ 16 μBq/kg ) will contain 100 tones of LAr, $^{222}\text{Rn} = \leq 1 \ \mu\text{Bq/m}^3$.

The cryostat is immersed in a water tank (590 t of water).

The Ge detector array is made up of individual detector strings and is situated in the central part of the cryostat.
The **ultra-pure water buffer** serves as a gamma and neutron shield and, instrumented with 66 photomultipliers, as Cherenkov detector **for efficiently vetoing** cosmic muons. Recent simulations show, that an **efficiency of more than 99 % can** be achieved, reducing the muon induced background to a level of $10^{-5}$ events/(keV $\cdot$ kg $\cdot$ y).

**Plastic scintillator panels** *(20 m$^2$, 20 x 2 = 40 modules)*
on top of the detector will tag muons which enter the cryostat through the neck.

For more details see “The GERDA Muon Veto Cherenkov Detector”, presented by Markus Knapp at the TAUP 2009 Poster Session.
The optimal for the GERDA purpose the **muon veto modules on the base of plastic scintillator** have been developed, assembled and tested.

(with the light collection non-uniformity less than 15 % for the 200 x 50 x 3 cm$^3$ dimensions).

It is shown that the **muon vetoing efficiency of about 98 %** can be achieved.
General Infrastructure of the GERDA set up

A cleanroom and radon tight lock on top of the vessel assembly allow to insert and remove individual detector strings without contaminating the cryogenic volume.
The main GERDA set up is currently under construction (starting from 2007) in the INFN Gran Sasso National Laboratory (LNGS), Italy, and the main parts of the “nested type” assembly have already installed in the deep underground facility at 3500 m w.e.
Clean room almost ready

Mounting PMT modules in water tank

May 2009

June 2009
• 8 enriched (IGEX and HdM) and 6 non-enriched crystals (GENIUS-TF)

The IGEX and HdM crystals were removed from their parent vacuum copper cryostats

• All detectors were refurbished by Canberra (no passivation layer !)

• The detectors were stored underground during reprocessing (HADES), (with less than 1 week exposure above ground).

• Each detector is equipped with a low-mass holder.
• Now they are stored at LNGS under vacuum in special transport containers
Testing of naked HPGe detectors in LN\textsubscript{2} / LAr

Long-term stability tests (3 HPGe detectors in LN\textsubscript{2}/LAr during 2 years)

tested in liquid Argon
FWHM $\sim2.5$keV (at 1332keV),
leakage current stable

Problems reported from GENIUS-TF
[H.V.Klapdor-Kleingrothaus end I.Krivosheina, NIM A556 (2006) 472]

have been overcome by GERDA.

Long term stability for $> 1$ year.
Detector performances are stable in LAr!
The main results achieved during modification of naked HPGe detectors and tests in LAr

1. It was shown that **naked Ge crystals can work directly in liquid argon** with the leakage current and energy resolution corresponding to their standard values in the traditional cryostats.

2. Their parameters **are stable during several months** after a few dozen cycles of removing and submerging from/in the LAr even after irradiation with intensive gamma sources (**modification without passivation layer**).

It shows the feasibility of the overall GERDA project.
To reach the background level required for the Phase II 10^{-3} \text{cts/(keV·kg·y)}, additional new methods are required to suppress the intrinsic background of the detectors.

1. Research and development are carried out to produce new segmented and BeGe types of germanium detectors which can resolve multi-site energy deposits.

2. Another effective approach is to discriminate multi-site deposits from the pulse shape analysis of the signal as well as to use anticoincidence between nearby detectors assembled in several strings.

3. The novel concept to use the LAr scintillation light as anti-coincidence signal for further background suppression is developed.
Phase-II detector candidate #1:

18-fold segmented detector

novel “snap contact” -> small amount of extra material

(19g Cu, 7g PTFE, 2.5g Kapton per each detector)

Segmented prototype detector tested in LN

$\Delta E/E$ (FWHM): core 4.1 keV, segments 3.6 - 5.7 keV

leakage current 30 ± 5 pA

This detector works in liquid nitrogen, stable performance for 5 months

For more details see
“First Time Ever: 18-fold Segmented HPGe Detector in LN2”, presented by Jing Liu at the TAUP 2009 Poster Session
Phase-II detector candidate # 2: BeGe (broad-energy) detector

modified model BE5030

the largest BEGe detector
commercially available from Canberra Semiconductor, N.V. Olen

Specifications from Canberra:
- depletion voltage: 4000 V
- FWHM @ 122 keV: 0.63 keV
- FWHM @ 1.33 MeV: 1.8 keV
- mass: 870 g

Parameters obtained during R&D for GERDA:
- depletion voltage: 3800 V
- FWHM @ 59.5 keV: 0.49 keV
- FWHM @ 1.33 MeV: 1.59 keV
- mass: 878 g
Phase-II detector candidates:
BEGe detector vs. 18-fold segmented detector

Comparison of discrimination power for $^{228}\text{Th}$ spectrum

**BEGe point-contact**
Fractions remaining after PSA cut:
- DEP $89.2\% \pm 0.9\%$
- 1.62 MeV $10.1\% \pm 0.7\%$
- 2.61 MeV $9.8\% \pm 0.4\%$
- ROI $Q_{\beta\beta} = 40.2\% \pm 1.6\%$

**18-fold segmented coax**
Fractions remaining after combined single-segment and PSA cut:
- DEP $81.93\% \pm 2.22\%$
- 1.62 MeV $18.98\% \pm 0.39\%$
- 2.61 MeV $14.57\% \pm 0.31\%$
- ROI $Q_{\beta\beta} = 48.10\% \pm 1.12\%$

(SASA data without Compton background subtraction)

SSE/MSE discrimination with BEGe is comparable with 18-fold segmented detector
Pilot set up MiniLArGe
for developing LAr scintillation methods

Dewar:  Ø29 cm, h=65 cm
        ≈ 60 kg LAr (43 L) total volume

Light detection: wavelength shifter/reflective foil
                (VM2000 + TPB/PST)
                + PMT(8”, ETL 9357-FLB )

Active volume:  Ø20 cm, h=43 cm
                ≈ 19 kg LAr (13.5 L)

Shielding:  5 cm lead (+ 10 cm BP for n)
             +15 mwe underground
It was shown that the LAr scintillator is a powerful tool to be used in the GERDA Phase II and III as:

1. **Gamma spectrometer** with large active volume
   (for direct measurement of gamma background inside the GERDA facility)

2. **Large volume Neutron detector**
   (for direct measurement of neutron background and neutron – gamma delayed (anti-) coincidence inside the GERDA facility)

3. **Radon detector / alpha-spectrometer**
   (for direct monitoring of Radon inside the GERDA facility)
MiniLArGe as Gamma-spectrometer

For MiniLArGe
ΔE/E (FWHM): 7,5 % at 1 MeV
comparable with NaI detectors
was achieved
MiniLArGe as Radon detector / Alpha-spectrometer

228\text{Th} + 222\text{Rn} – ratio s/f vs. energy

2.6 \text{ MeV} \\
208\text{TI-\gamma}

\gamma

\alpha

Energy [channels]
MiniLArGe as Neutron detector

AmBe (neutron+gamma) source
Neutron flux is $2 \times 10^3$ 1/sec

Th-228 gamma sources

The LArGe Setup
with 1.3 tons of LAr

- **Lock**: Can house up to 3 strings (9 detectors)
- **9 PMTs**: 8” ETL9357
- **VM2000 & wavelength shifter**
- **Cryostat**: Inner diameter: 90 cm, Volume: **1000 liter**
- **Shield**: Cu 15 cm, Pb 10 cm, Steel 23 cm, PE 20 cm
LAr scintillation veto by tagging extra energy in LAr


Factor 300 reduction in ROI
**LArGe** was assembled and testing in the day surface lab.

Ready to go to LNGS underground facility GDL
Outlooks & Plans

Final assembling of the LArGe test facility is planned on Autumn 2009. It is planned to perform the test & background measurements in this facility. The commissioning of the main GERDA setup at LNGS will start from September 2009.

Phase I (2009 – 2011):
After 1 year of data taking (an exposure of 15 kg x y), with the background $10^{-2}$ counts/(keV kg y),
the GERDA can either confirm the claimed observation of $\beta\beta0\nu$ decay or refute it at the high statistical level without problems with uncertainties in NME. If no events will be observed, the limit on the half life would amount to $T_{1/2} > 3 \times 10^{25}$ y or, translated into an effective neutrino mass, $m_\nu < 0.2 - 0.9$ eV, depending on NME used (for instant, $m_\nu < 194$ meV corresponds to $|M_{0\nu}| = 5.46$ from the recent paper: J. Barea and F. Iachello, Phys.Rev. C 79, 044301 (2009))

Phase II (from 2011):
The total mass with the new types of $^{76}$Ge detectors will be 40 kg. After exposure of 100 kg x years and with the background reduced up to $10^{-3}$ counts/(keV kg y), the limit on $T_{1/2}$ would improve to $> 1.5 \times 10^{26}$ y. This translates to an upper limit on the effective neutrino mass of 0.08 - 0.29 eV.

Phase I will cover the area of sensitivity required to scrutinize the claim and Phase II will cover the degenerate neutrino mass hierarchy.
Phase III:
A ton scale $^{76}\text{Ge}$ experiment
with further background reduction up to $10^{-4}\text{counts/(keV}\_\text{kg}\_\text{y})$
undertaken in the worldwide GERDA-MAJORANA collaboration
will be required to cover the inverted hierarchy region.

The full scale GERDA-MAJORANA experiment is proposed to start from 2014.
The GERDA collaboration consists of about 90 physicists from 14 institutions coming from 6 countries

**GERDA Collaboration**

- INFN LNGS, Assergi, Italy
- JINR Dubna, Russia
- MPIK, Heidelberg, Germany
- Univ. Köln, Germany
- Jagiellonian University, Krakow, Poland
- Univ. di Milano Bicocca e INFN, Milano, Italy
- INR, Moscow, Russia
- ITEP Physics, Moscow, Russia
- Kurchatov Institute, Moscow, Russia
- MPI, München, Germany
- Univ. di Padova e INFN, Padova, Italy
- Univ. Tübingen, Germany
- IRMM, Geel, Belgium
- University Zurich, Switzerland

**90 physicists / 14 institutions / 6 countries**

http://www.mpi-hd.mpg.de/ge76
Back up slides