The GERDA Experiment: Status and Perspectives

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1. The GERDA experiment
   - short introduction
2. Status of Phase I
   - installation
   - first measurements
3. Perspectives for Phase II
   - the detectors
   - R&D
Search for the half-life of the $0\nu\beta\beta$-decay of $^{76}\text{Ge}$

$$2\nu\beta\beta: (A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$$

$$0\nu\beta\beta: (A,Z) \rightarrow (A,Z+2) + 2e^-$$

Majorana nature
Physics beyond SM
Absolute mass scale
- Hierarchy: degenerate, inverted or normal
- (effective) neutrino mass

Best limits on $0\nu\beta\beta$-decay used $^{76}\text{Ge}$ (86%) (IGEX & Heidelberg-Moscow):
$$T_{1/2} > 1.9 \times 10^{25} \text{y} \ (90\% \text{CL})$$
(& $6\sigma$ claim for evidence)
Sensitivity of the GERDA Experiment

\[ T_{1/2}^{0\nu}(y) > \frac{\log 2 \cdot N_A \cdot \varepsilon \cdot k_{\text{enr}}}{k_{\text{CL}}} \cdot \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \]

- well established enrichment technique (reasonable cost for > 80%)
  \( \Rightarrow \) enrichment \( k_{\text{enr}} = 86\% \, ^{76}\text{Ge} \)
- established detector technologies
  \( \Rightarrow \) large total mass \( M \) (expandable)
- very good energy resolution:
  \( \Rightarrow \) small \( \Delta E \sim 2\text{-}3 \, \text{keV} \)
- very good detection efficiency because detectors made of source material
  \( \Rightarrow \varepsilon \sim 1 \)
- detector-grade semiconductors are high-purity materials (low background)
  \( \Rightarrow \) small direct contribution to the background index \( B \)

Optimize the parameters

- Bare \( ^{\text{enr}}\text{Ge}-\text{diodes array in LAr} \)
  +
- Shield: high-purity LAr/H\(_2\)O
## Background Sources in the GERDA Experiment

<table>
<thead>
<tr>
<th>Source</th>
<th>B [10^{-3} cts/(keV kg y)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ext. $\gamma$ from $^{208}$Tl ($^{232}$Th)</td>
<td>$&lt;1$</td>
</tr>
<tr>
<td>Ext. neutrons</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Ext. muons (veto)</td>
<td>$&lt;0.03$</td>
</tr>
<tr>
<td>Int. $^{68}$Ge ($t_{1/2}$ = 270 d)</td>
<td>12</td>
</tr>
<tr>
<td>Int. $^{60}$Co ($t_{1/2}$ = 5.27 y)</td>
<td>2.5</td>
</tr>
<tr>
<td>$^{222}$Rn in LAr</td>
<td>$&lt;0.2$</td>
</tr>
<tr>
<td>$^{208}$Tl, $^{238}$U in holder</td>
<td>$&lt;1$</td>
</tr>
<tr>
<td>Surface contamination</td>
<td>$&lt;0.6$</td>
</tr>
</tbody>
</table>

**Target values:**
- **Phase I:** $B < 10^{-2}$ cts/(keV· kg· y)
- **Phase II:** $B < 10^{-3}$ cts/(keV· kg· y)

**Muon veto**
- 180 days exposure after enrichment + 180 days underground storage
- 30 days exposure after crystal growing

208Tl, 238U in holder
Background Reduction in the GERDA Experiment

Suppression of $\mu$-flux $> 10^6$

Background reduction methods

- Underground laboratory
- Material cleaning
- Passive shield (Cu&Pb&LAr)
- Muon veto

Pulse shape analysis vs. detector segmentation
- Detector anti-coincidence
- R&D: LAr scintillation
Phase I:
- 18 kg of enriched Ge
- 1 year exposure
- After 1 year, able to verify the KK claim

Phase II:
- 40 kg of enriched Ge
- 3 years exposure
- KKDC claim

Phase III (GERDA+Majorana):
- 1 ton experiment → ~50 meV

Mass hierarchy:
- Normal: $\Delta m^2_{23} > 0$
- Inverted: $\Delta m^2_{23} < 0$
- Degenerate: $\Delta m^2_{23} = 0$

GERDA Phase I - after 1 year able to verify the KK claim
Status of Phase I

- clean room - rdy
- cryo-mu-lab
- control room
- water plant
- Rn monitor
- GERDA bldg - rdy

- phase I lock - single-string arm
- phase I array rdy
- cryostat - rdy
- water tank - rdy
- DAQ room
- FE electronics 2 version avlb
- μ veto rdy
- water plant
Mounting of GERDA

Unloading of vacuum cryostat (6 Mar 2008)
Produced from selected low-background austenitic steel

Construction of water tank
$\varnothing = 10 \text{ m}$
$H = 9.5 \text{ m}$
$V = 650 \text{ m}^3$

Construction of clean room

Muon veto completed

27 Feb 09

19 May 08

Aug 09
Phase I Detectors

- 8 $^{enr}\text{Ge}$ (HdM&IGEX) + 6 $^{nat}\text{Ge}$ (GTF) p-type coaxial Ge detector refurbished
- $^{enr}\text{Ge}$ mass: 1-3 kg (total 17.9 kg)
- $C_{det} = 30\text{--}40$ pF
- deployed in strings of 3 dets.
- mounted in low-mass Cu holders
- HV contact: on Li surface by pressure
- readout contact: in borehole spring-loaded
- all the detectors have been tested naked in LAr and perform well (I-V & R < 3 keV @ 1.332 MeV).
- **Long term stability experimentally proved**
Stability of Phase I Detectors in LAr/LN₂

Apparent problem* of 'Limited long-term stability of naked detectors in liquid nitrogen as result of increasing leakage current' resolved by GERDA:

• operated 3 HPGe detectors in LN/LAr
• 2 years of experience, >50 cycles

► with proper procedure no problem, in contradiction to claim*

* Klapdor-Kleingrothaus & Krivosheina, NIM A566 (2006) 472

no deterioration after 1 year of operation in LAr
M. Barnabé-Heider, PhD thesis '09
Commissioning with $^{\text{nat}}$Ge Det.-Running NOW

• Summer/autumn 2009: integration test of phase I detectors, FE, lock, DAQ, LAr dewar
  ⇒ energy resolution ~ 2.7 keV @ 1332 keV

• Apr/May 2010: Installation of single-string lock in the GERDA cleanroom
• May 2010: Deployment of FE & detector mock-up, followed by first deployment of a of non-enriched det.
• June 2010: Water tank filling

• June 2010: Commissioning run with 3 $^{\text{nat}}$Ge detectors
• four cooling cycles made until now
• grounding problems
• characterization runs with Th source
• optimizing energy reconstruction algorithms from digital data
• long-term background measurement are in progress
nat Ge Detectors in LAr - $^{228}$Th source

- GTF 45: 4.4 keV FWHM
- GTF 32: 4.0 keV FWHM
- GTF 112: 4.2 keV FWHM

Pulser
# Operation of the 3 $^{\text{nat}}$Ge Detectors String

<table>
<thead>
<tr>
<th>Date</th>
<th>Detector</th>
<th>Signal cable length</th>
<th>FWHM [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pulser</td>
</tr>
<tr>
<td>11/07/2010</td>
<td>GTF 45</td>
<td>~35 cm</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>GTF32</td>
<td>~50 cm</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>GTF112</td>
<td>~65 cm</td>
<td>3.1</td>
</tr>
</tbody>
</table>

- July 16 start of background measurement with Flash ADC (FWHM ~ 5 keV)
- pulser at 0.1 Hz
- Muon veto signal recorded with the Flash ADC

- No indication of background from U/Th/Co
- Clear peak at 1524 keV (line from $^{42}$Ca)
42Ar Background ‘Dilema’

Measurements in LArGe with BEGe
- 10 times more 42Ar activity with GTF (in GERDA and LArGe setups)
- even more

Study of the problem:
- origin of the effect
- possible solutions to reduce it

Mounted a mini-shroud around the 3 detectors in the GERDA setup
- reduction of the effect

More work needed with both setups: LArGe and GERDA

A.S. Barabash,
Proc. Int. Workshop on Technique and Application of Xenon Detectors 2002
42Ar/Ar = 3 x 10^{-21}
**R&D for Phase II Detectors**

BEGe type detectors were chosen for the Phase II of the GERDA experiment

- good energy resolution and noise characteristics
- excellent rejection capability of discrimination between single-site and multiple-site events based on PSD analysis
- simpler electronic configuration as compared to segmented detectors / less background due to the reduced number of FE electronics channels and less cables

Presently tests are run with 2 \(^{\text{depl}}\text{Ge}\) and 3 \(^{\text{nat}}\text{Ge}\) BEGe detectors
Discrimination based on A/E Parameter

A = maximal current signal amplitude
E = energy of the event

A/E for SSE is independent of the energy and the interaction location inside the crystal volume.

A/E for MSE is smaller

D. Budjas et al., JINST 4 P10007 (2009)
M. Agostini et al., to be published

PSD cut - 90% of the $^{208}$Tl 2614 keV DEP
Test of BEGe performance in LArGe

First test of a naked BEGe detector in LAr (LArGe test bench)

- Maintains its spectroscopic characteristics
- Good PSA
- Importance of the LAr veto for the reduction of the $\gamma$-ray backg. (R&D needed for Phase III)
Construction of GERDA is concluded
- The cryostat and the water tank were filled
- Since June 2\textsuperscript{nd} commissioning runs with Phase I $^{\text{nat}}$Ge detectors and the single-string arm are in progress
- Long-term background measurements are presently running with $^{\text{nat}}$Ge GTF detectors
- By November the 3-strings lock will be installed and it will be tested with mockup and $^{\text{nat}}$Ge detectors
- Mounting of the enriched detectors depends on the results from these measurements
- Presumably first results from Phase I will be available in 2011
- The R&D for the Phase II BEGe detectors development is running in parallel with the preparation of Phase I
- The BEGe detector was chosen for the Phase II due to its excellent noise and PSD characteristics

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Collaboration

~ 100 members
18 institutions
7 countries

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