Status of the GERDA Experiment

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OUTLINE:

• A short GERDA history: Design and construction
• First background data: Understand the unexpected
• Background mitigation: control the unexpected
• First results with enriched detectors
• Installation of Phase I detectors: start of physics runs
• Plans for phase II: new detectors
**GERDA design: Use HP\(^{76}\text{Ge}\) detectors**

<table>
<thead>
<tr>
<th>Source = (^{76}\text{Ge} = \text{Detector})</th>
<th>High signal detection efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector material very pure (zone refinement, Czochralski growth)</td>
<td>Very low intrinsic internal background</td>
</tr>
<tr>
<td>Very good energy resolution</td>
<td>Background due to 2νββ decay negligible</td>
</tr>
<tr>
<td>Considerable experience</td>
<td>Industrial production, improvements possible</td>
</tr>
<tr>
<td>Natural abundance of (^{76}\text{Ge}) 7,44%</td>
<td>Enrichment necessary</td>
</tr>
</tbody>
</table>
GERDA design:

- Clean room
- Lock system
- Detector array
- Cryostat with internal Cu shield
- Water tank with HP water and μ-veto
- HP liquid Ar
GERDA design:

Location: Hall A of LNGS, Assergi, Italy
3500 mwe

Phase I: Use HdM and IGEX detectors
Phase II: Convert 37.5 kg of enriched germanium (87% $^{76}$Ge) into detectors
GERDA design:
phase I Detectors (from HdM and IGEX) after dismounting from cryostats:

- ANG1: 958g
- ANG2: 2833g
- ANG3: 2391g
- ANG4: 2372g
- ANG5: 2746g
- RG1: 2110g
- RG2: 2166g
- RG3: 2087g

Total mass: 17.66 kg
GERDA construction:
GERDA construction:

Preliminary infrastructure for deployment of three detectors completed in June 2010

Full phase I infrastructure for deployment of 12 detectors (all HdM and IGEX plus reference detectors) completed in May 2011
Deployment of first string:

First detectors three (natural) deployed in June 2010
First calibration data:

Detectors:  
- GTF 45: 2334 g  
- GTF 32: 2321 g  
- GTF 112: 2967 g

FWHM @ 2.6 MeV: ~ 4.0 keV (<0.2%)
First background data:

Understand the unexpected:

$^{42}\text{K}$ ions have long life time in LAr (half life: 12.4 hours)

→ Drift in E-field

→ attracted to surfaces close to or on detector
First background data:
Background mitigation: control the unexpected

→ Mini Shroud (MS) against $^{42}\text{K}$ drift close to detector

→ Try Different field configurations to repel ions from detectors (HV or GND on MS, …)

Shroud against convection ($^{222}\text{Rn}$)
First background data:
Background mitigation: control the unexpected

Effect of mini shroud

Without mini shroud

With Mini shroud

counts/(keV x kg x year)

Energy (keV)
First background data:
Background mitigation: control the unexpected

Without mini-shroud (Run 1-3): 0.169 counts/ (kg y keV)

With mini-shroud (Run 4): 0.074 counts/(kg y keV)

Run with “lowest BI” (Run 6): 0.04±0.02 counts/(kg y keV)
First background data:

Background lines in (not yet “optimized”) runs 10,11,12 (1.6 kg y) and comparison with Heidelberg Moscow experiment (71.7 kg y)

<table>
<thead>
<tr>
<th>isotope</th>
<th>energy [keV]</th>
<th>$I_{HdM}$ original [cnts]</th>
<th>$I_{HdM}$ normalized</th>
<th>$I_G$ [cnts]</th>
<th>$R$</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}$K</td>
<td>1460.8</td>
<td>13010 ± 134</td>
<td>287 ± 3</td>
<td>14.6 ± 5.8</td>
<td>19.7 ± 7.9</td>
<td>$^{232}$Th</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>1173.2</td>
<td>3955 ± 88</td>
<td>87 ± 2</td>
<td>12.8 ± 5.8</td>
<td>6.8 ± 3.1</td>
<td>$^{238}$U</td>
</tr>
<tr>
<td></td>
<td>1332.3</td>
<td>3690 ± 90</td>
<td>81 ± 2</td>
<td>&lt; 7.9</td>
<td>&gt; 10</td>
<td></td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>661.6</td>
<td>20201 ± 164</td>
<td>445 ± 4</td>
<td>&lt;2.5</td>
<td>&gt; 180</td>
<td></td>
</tr>
<tr>
<td>$^{208}$Tl</td>
<td>583.1</td>
<td>2566 ± 228</td>
<td>57 ± 5</td>
<td>9.9 ± 5.8</td>
<td>5.7 ± 3.4</td>
<td>$^{232}$Th</td>
</tr>
<tr>
<td></td>
<td>2614.5</td>
<td>1184 ± 36</td>
<td>26 ± 1</td>
<td>7.0 ± 3.8</td>
<td>3.7 ± 2.0</td>
<td></td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>609.3</td>
<td>7552 ± 96</td>
<td>167 ± 2</td>
<td>36.7 ± 8.1</td>
<td>4.6 ± 0.8</td>
<td>$^{232}$Th</td>
</tr>
<tr>
<td></td>
<td>1120.3</td>
<td>1926 ± 86</td>
<td>43 ± 2</td>
<td>12.2 ± 5.5</td>
<td>3.5 ± 1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1764.5</td>
<td>2204 ± 51</td>
<td>49 ± 1</td>
<td>7.0 ± 3.8</td>
<td>6.9 ± 3.8</td>
<td></td>
</tr>
<tr>
<td>$^{228}$Ac</td>
<td>910.8</td>
<td>2135 ± 115</td>
<td>47 ± 3</td>
<td>&lt;7.7</td>
<td>&gt; 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>968.9</td>
<td>1259 ± 82</td>
<td>28 ± 2</td>
<td>&lt;6.4</td>
<td>&gt; 4.8</td>
<td></td>
</tr>
</tbody>
</table>

→ Most important background peaks significantly less intense!
First deployment of enriched detectors:

Deployed three detectors enriched in 76Ge in June 2011 together with 4 natural HPGe detectors.
First results with enriched detectors:

Low energy spectrum with enriched HPGe detectors

$^{39}\text{Ar} - 1.01 \text{ Bq/kg}$

$^{76}\text{Ge} - 1.74 \cdot 10^{21} \text{ y}$

$^{42}\text{Ar}$ spectrum normalized to peak assuming homogeneous distribution

$2\nu\beta\beta$-decay clearly detectable after two weeks of measurement!
First results with enriched detectors:

Energy vs. Time, single detector, muon veto, no pulse shape analysis!

RoI ± 200 keV: \(0.081^{+0.028}_{-0.020}\) cts/(kg y keV)

RoI ± 100 keV: \(0.047^{+0.021}_{-0.023}\) cts/(kg y keV)

3 enriched and 4 natural detectors

17.3 kg

0.75 kg y
First results with enriched detectors:

Energy vs. Time, single detector, muon veto, no pulse shape analysis!

3 enriched detectors: 6.7 kg 0.29 kg y

RoI ± 200 keV: $0.035^{+0.021}_{-0.015}$ cts/(kg y keV)

RoI ± 100 keV: $0.017^{+0.029}_{-0.012}$ cts/(kg y keV)
Installation of phase I detectors:
Installation of phase I detectors:

Phase I of GERDA started on 1.11.11!

Now measuring!

Data will be blinded in ROI

Béla Majorovits
Installation of phase I detectors:

$^{228}$Th calibration measurement
# Installation of phase I detectors: $^{228}$Th calibration measurement

<table>
<thead>
<tr>
<th>Detector</th>
<th>Total mass, g</th>
<th>$HV_{dep}$ V</th>
<th>HV, V</th>
<th>FWHM (2.6 MeV)</th>
<th>LC, pA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MCA</td>
<td>FADC</td>
</tr>
<tr>
<td><strong>Enriched</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANG 1</td>
<td>958</td>
<td>3000</td>
<td>4000</td>
<td>3.6</td>
<td>3.8</td>
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<tr>
<td>ANG 2</td>
<td>2833</td>
<td>3000</td>
<td>3500</td>
<td>4.4-4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>ANG 3</td>
<td>2391</td>
<td>3000</td>
<td>3500</td>
<td>4.4-4.6</td>
<td>4.9</td>
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<tr>
<td>ANG 4</td>
<td>2372</td>
<td>2800</td>
<td>3200</td>
<td>4.0-4.5</td>
<td>4.4</td>
</tr>
<tr>
<td>ANG 5</td>
<td>2746</td>
<td>1000</td>
<td>2000</td>
<td>4.0</td>
<td>4.2</td>
</tr>
<tr>
<td>RG 1</td>
<td>2110</td>
<td>4200</td>
<td>4500</td>
<td>4.4-4.5</td>
<td>4.8</td>
</tr>
<tr>
<td>RG 2</td>
<td>2166</td>
<td>3800</td>
<td>4000</td>
<td>4.7-5.0</td>
<td>5.1</td>
</tr>
<tr>
<td>RG 3</td>
<td>2087</td>
<td>3300</td>
<td>3300</td>
<td>5.4 (6 μs)</td>
<td>6.1</td>
</tr>
<tr>
<td><strong>Non-enriched</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTF 112</td>
<td>2957</td>
<td>2000</td>
<td>3000</td>
<td>3.7</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Plans for phase II: new detectors
BEGe for improved background recognition

- Drift paths in point contact detectors are long
- Weighting potential is large around point contact and small in the rest of the detector
- Small “point contact”
  - Low capacity
  - Improved energy resolution: 1.6 keV @ 1.3 MeV!

→ Very pronounced structures for individual energy deposits
→ Improved multi site recognition efficiency by A/E parameter

D. Budjas et al., JINST 4 P10007 (2009)
Plans for phase II: new detectors
Background recognition powers of BEGes

Identify surface events:
Data taken with $^{90}$Y $\beta$-source $\rightarrow$ n+ surface events

$\rightarrow$ Low E-fields in “partially” dead layer
$\rightarrow$ Slow pulses
$\rightarrow$ Decrease A/E parameter
Plans for phase II: new detectors
Background recognition powers of BEGes

\[ 2^{28}\text{Th source} \]

At p+ contact also e\(^-\) are “visible”
\[ \rightarrow A_{\text{max}}/E \text{ is increased} \]

M. Agostini et al., JINST 6 P03005 (2011)
Plans for phase II: new detectors
BEGe for improved background recognition

55 kg enriched germanium in form of GeO₂

Reduction to metal ingots:

35.5 kg zone refined 6N enriched germanium for crystal pulling

36.5 kg enriched germanium in form of ingots

Crystal pulling using Czochralski technique

Production of HP⁻¹⁻⁻ Ge detectors.

Production chain has been tested and established using depleted germanium

→ 5 working HP⁻⁰⁻⁻ Ge detectors available
Plans for phase II: new detectors
Transport of enriched metal ingots to Canberra US

Transport in shielded container:
70cm iron, 70cm salt-water
Plans for phase II: new detectors
Transport of enriched metal ingots to Canberra US

Delivered enriched germanium to Canberra, US on 14th of October. Crystal production started on 17th of October

While not being processed enriched germanium is stored in cave
Plans for phase II: new detectors

Background rejection by detection of LAr scintillation light

Signal:

Background:

Liquid Argon

128nm scintillation light

To light detector
Plans for phase II: new detectors
Background rejection by detection of LAr scintillation light

<table>
<thead>
<tr>
<th>source</th>
<th>position</th>
<th>suppression factor</th>
<th>LAr veto</th>
<th>PSD</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{60}$Co</td>
<td>int</td>
<td>27 ± 1.7</td>
<td>76 ± 8.7</td>
<td>3900 ± 1300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ext</td>
<td>3.2 ± 0.2</td>
<td>4.4 ± 0.4</td>
<td>18 ± 3</td>
<td></td>
</tr>
<tr>
<td>$^{228}$Ra</td>
<td>int</td>
<td>4.6 ± 0.2</td>
<td>4.1 ± 0.2</td>
<td>45 ± 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ext</td>
<td>25 ± 1.2</td>
<td>2.8 ± 0.1</td>
<td>129 ± 15</td>
<td></td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>int</td>
<td>1180 ± 250</td>
<td>2.4 ± 0.1</td>
<td>5200 ± 1300</td>
<td></td>
</tr>
</tbody>
</table>
### Design sensitivities

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Background</th>
<th>Limit $T_{1/2}$</th>
<th>Limit $&lt;m_{\beta\beta}&gt;$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 (Phase I)</td>
<td>$10^{-2}$</td>
<td>$&gt;2 \cdot 10^{25}$</td>
<td>$&lt;270$</td>
</tr>
<tr>
<td>100 (Phase II)</td>
<td>$10^{-3}$</td>
<td>$&gt;1.4 \cdot 10^{26}$</td>
<td>$&lt;110$</td>
</tr>
</tbody>
</table>

#### Diagram

- **GERDA I, II**
  - Inverted hierarchy
  - Degenerate
  - Disfavoured by $0\nu2\beta$
- **GERDA III**
  - Normal hierarchy
  - Disfavoured by cosmology

- **K.K. Claim**
- **90% CL (1 dof)**
- **Lightest neutrino ($m_1, m_3$) in eV**

**Phase II**

**90% prob. lower limit $T_{1/2}$ [$10^{25} y$]**

![Graph showing design sensitivities](image)
Conclusions:

• GERDA infrastructure ready since 2010
• $^{42}\text{K}$ background reduced by Mini shroud and field free configuration
• Enriched LE spectra are dominated by $39\text{Ar}$, $2\nu\beta\beta$ and $^{42}\text{K}$
• GERDA phase I started on 1.11.11
• Phase II detector crystals presently being pulled
• Improved background rejection efficiency $\rightarrow$ improve sensitivity
• LAr scintillation light detection will be implemented in phase II
First results with enriched detectors:

Spectrum between 550 keV and 1500 keV dominated by $2\nu\beta\beta$-decay of $^{76}\text{Ge}$ – 1.74 •