The GERmanium Detector Array

Outline:
• Exp. issues of 0νββ-decay of $^{76}$Ge
• Concept of GERDA
• Status of the experiment
• Summary and conclusions

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Experimental issues of $0\nu\beta\beta$-decay of $^{76}\text{Ge}$

- **Detection principle:** measure ionization energy inside detector
- **Observable:**
  - number of events at Q-value
  - half-life ($T_{1/2} \gtrsim 1.6 \cdot 10^{25}$ y)
  - Majorana $\nu$ mass ($m \lesssim 0.3$ eV)
- **Expect O(10-20) signal events**
- **Background reduction drives design of the experiment**
- **About 35 candidate isotopes,** here: $^{76}\text{Ge}$

$0\nu\beta\beta$: (2039 keV)

$2\nu\beta\beta$
Previous (and recent) experiments

IGEX (CanFranc)
- Enriched Ge detectors
- Total exposure ~8.87 kg·y
- **No signal observed**
- \( T_{1/2} > 1.57 \cdot 10^{25} \text{ y} \)

Heidelberg-Moscow (INFN)
- Enriched Ge detectors
- Total exposure ~71.7 kg·y
- \( T_{1/2} > 1.9 \cdot 10^{25} \text{ y} \)
- Part of collaboration: **claim**
- \( T_{1/2} = 1.2 \cdot 10^{25} \text{ y} \)
High-purity germanium crystals as **source and detector**

Germanium can be used as semiconductor detector at ~80 K
Measure ionization energy in shielded detector
High signal efficiency 86% - 96%

**Operation of detectors directly inside a cryogenic liquid**


**Reduction of background to** $10^{-3}$ **counts/(kg·keV·y)**

Minimize radioactive contaminations close to the detectors
Use of **segmented germanium detectors in second phase**

2 orders of magnitude below that of previous experiments

**Sensitivity aimed at:** **200 meV** (limit) at an exposure of 100 kg·y
GERDA @ LNGS

1400 m
~ 3,800 m.w.e

LNGS

Hall A
Technical realization

Clean-room
Muon veto (S)
Lock system

Water tank (steel)
Muon veto (Č)
Cryostat (steel + Cu)
Liquid argon

Detector array
Phase I detectors

• Use enriched detectors from HdM and IGEX experiments (prev. stored at LNGS / CanFranc)

• Need to be refurbished and mounted into new holders

• All detectors were tested and perform well

• Energy resolution
  ~ 2-3 keV (at 1.3 MeV)

• Mass 1-3 kg, total ~ 18 kg

• Refurbishment in progress
Phase II detectors

- 37.5 kg germanium enriched in $^{76}\text{Ge} \sim 88\%$
- Stored underground (avoid cosmic rad.)
- Next: purification, crystal pulling, detector manufacturing

Phase II prototype

Germanium delivery

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Phase I:
18 kg germanium
20 kg·y exposure
$10^{-2}$ counts/(kg·keV·y)

Phase II:
35 kg germanium
100 kg·y exposure
$10^{-3}$ counts/(kg·keV·y)

Phase III:
500 kg germanium
<10$^{-3}$ counts/(kg·keV·y)

**Background:** processes which cause energy deposition at Q-value

- Cosmogenic production of radioactive isotopes
  - Cosmic muons
  - Neutrons:
    - Muon induced
    - From radioactive isotopes in the rock
  - Radioactive isotopes in the surrounding:
    - Electrons/positrons
    - Photons
    - Alphas (surface)

**Detector production and storage**

**Background units:**
- counts / (kg·keV·y)

- Choice of material close to detectors
- Purity of the liquid argon
- Depth and laboratory dependent
- Total mass around $Q_{\beta\beta}$
- Measuring time
Rejection techniques

- Rejection principle: study volume over which energy is distributed ($e/\gamma$)
- Detector anti-coincidences
- Segmented detectors *(poor man’s pixilation)*
- Analysis of the detector response function *(pulse shape analysis)*
- R&D: active liquid argon veto *(use of scintillation light)*

Successful R&D program:

I. Abt et al. NIMA 577 (2007) 574
I. Abt et al. arXiv:0704.3016 (accepted by EPJC)
I. Abt et al. arxiv:nucl-ex/0701005 (sub. to NIMA)
I. Abt et al. NIMA 570 (2007) 479
## Background estimate

### MC simulation of 21 detectors with 18-fold segmentation

<table>
<thead>
<tr>
<th>Part</th>
<th>Background contribution [10^{-4} \text{ counts/(kg\cdot keV\cdot y)}]</th>
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<tbody>
<tr>
<td>Detector</td>
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</tr>
<tr>
<td>$^{68}\text{Ge}$</td>
<td>10.8</td>
</tr>
<tr>
<td>$^{60}\text{Co}$</td>
<td>0.3</td>
</tr>
<tr>
<td>Bulk</td>
<td>3.0</td>
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<tr>
<td>Surf.</td>
<td>3.5</td>
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<tr>
<td>Holder</td>
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<tr>
<td>Cu</td>
<td>1.4</td>
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<tr>
<td>Teflon</td>
<td>2.0</td>
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<tr>
<td>Cabling</td>
<td>7.6</td>
</tr>
<tr>
<td>Electronics</td>
<td>3.5</td>
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<tr>
<td>Liquid nitrogen</td>
<td>0.1</td>
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<tr>
<td>Infrastructure</td>
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<tr>
<td>Muons and neutrons</td>
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<tr>
<td>Total</td>
<td>37.1 (30.6)</td>
</tr>
</tbody>
</table>

Gain through segmentation factor $\sim 10$

Reducible via PSA

Redesign: Reduced material

Will change with $l$. argon
Status

• **Construction has started**
  • 2007/08: water tank and cryostat installation
  • 2008: clean-room installation
  • early 2009: commissioning
Summary and conclusions

• GERDA is currently being built with the aim to search for neutrinoless double beta-decay
• Detector concept: germanium detectors submerged into liquid argon
• Reduction of background is the most critical issue
• Background rejection techniques have been shown to work (segmentation, pulse shape analysis, liquid argon veto, etc.)
• Construction is ongoing
• Commissioning expected early 2009
• Expected sensitivity: 13.5 \times 10^{25} \text{y} (200 \text{meV}) with 100 \text{kg}\cdot\text{years exposure and background of } 10^{-3} \text{ counts/(kg}\cdot\text{keV}\cdot\text{y)}
Neutrino mass sensitivity

Assuming $\langle M^2 \rangle = 2.40$ (Nucl. Phys. A 766 (2006) 107)
Neutrino mass and hierarchy

- Lightest neutrino mass [eV]
- Effective Majorana neutrino mass [eV]
- Disfavored by GERDA (expected)
- \(\sin^2 2\theta_{13} = 0\)
- \(\Delta m_{31}^2 < 0\)
- \(\Delta m_{31}^2 > 0\)

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