Background suppression in GERDA Phase II
and its study in the LARGE low background set-up

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http://www.mpi-hd.mpg.de/GERDA
Modified Broad-Energy Ge detectors

GERDA Phase I: semi-coaxial Ge detector

GERDA Phase 2: modified BEGe detector

**BEGe advantages:**

1) smaller p⁺ electrode ⇒ less capacitance ⇒ **less noise** ⇒ better energy resolution

2) favourable internal electric field distribution ⇒ **powerful PSD capability**

- narrow peak in current signal
- signal shape independent of interaction position (same final trajectory)
- current amplitude depends only on energy of interaction (~95% of volume)

**Dušan Budjáš (TUM)** [D. Budjáš et al., JINST 4:P10007,2009] [M. Agostini et al., JINST 6:P03005, 2011]
GERDA Phase II background identification tools

- Identification and discrimination of events by PSD and LAr veto:

  ββ-decay: β range in Ge ~mm
  γ-ray backgrounds: range in Ge ~cm

- Single-site event (SSE)
- Constant A/E

- Multi-site event (MSE)
- Reduced A/E

- Identification and discrimination of events by PSD and LAr veto:

  - α, β (Ra chain, 42K)
  - γ (Th, Ra chains)
  - γ+β (60Co, 68Ga)
  - Reduced A/E

- Surface backgrounds:
  - NSP
  - PCP
  - Contact pulse

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Background rejection using A/E cut with BEGes

A/E distribution from $^{228}$Th source

- **SSE** concentrated in a straight band
- **MSE region**
- **PSD cut**

- **DEP** 1593 keV
  - mostly SSE
  - 0νββ proxy
  - 90% survival

- **FEP** 1621 keV
  - mostly MSE
  - background
  - 10% survival

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PSD and LAr veto studies in LARGe

Low background test facility GERDA-LARGe at LNGS:

- Reflecting foil with wavelength shifter
- BEGe
- LAr
- PMTs

[228\text{Th} \text{near}]

- Without Cut
- PSD Cut
- LAr Veto Cut
- PSD + LAr Veto Cut

[228\text{Th} \text{far}]

- Without Cut
- PSD Cut
- LAr Veto Cut
- PSD + LAr Veto Cut

[226\text{Ra} \text{near}]

- Without Cut
- PSD Cut
- LAr Veto Cut
- PSD + LAr Veto Cut

[60\text{Co} \text{near}]

- Without Cut
- PSD Cut
- LAr Veto Cut
- PSD + LAr Veto Cut

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[M. Heisel, Dissertation, University of Heidelberg (2011)]
Production of $^{42}\text{Ar}$ for studying $^{42}\text{K}$ background

- $^7\text{Li}^{3+}$ irradiation; reaction: $^{40}\text{Ar}(^7\text{Li},\alpha \text{ p})^{42}\text{Ar}$
- Target cell with 500 mbar Ar gas
- Activated Ar inserted into LARGE

Tandem accelerator MLL Garching

Sample #2 spectra

- $^{44}\text{Sc}$ 271 keV
- $^{44}\text{Sc}$ 1157 keV
- $^{41}\text{Ar}$ 1293 keV
- $^{42}\text{K}$ 1524 keV
- 511 keV

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42K suppression methods studied in LARGe

**Step 1: preventing 42K ions collection at detector surfaces**

- **AC-coupled read-out** ⇒ outer electrode grounded, inner electrode shielded ⇒ “field-free”
- **Electrostatic shielding** (mesh on HV potential) ⇒ repelling ions and collecting them away from detector
- **Hermetic shroud** (transparent to XUV for LAr scintillation veto) ⇒ block ions from reaching detector

**AC coupling high-voltage capacitor (radiopure)**

- Suppression by factor 8
- Suppression by factor ~10
- Measurement ongoing

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42K suppression methods studied in LARGe

Step 2: reject the remaining 42K background via PSD
## GERDA Phase II background summary

### Background goal:
\[ < 10^{-3} \text{ cts/(keV\cdot kg\cdot yr)} \]

<table>
<thead>
<tr>
<th>background</th>
<th>without cuts [cts/(keV\cdot kg\cdot yr)]</th>
<th>PSD survival</th>
<th>LAr veto survival</th>
<th>after cuts [cts/(keV\cdot kg\cdot yr)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{208}\text{Tl} \ (\gamma)$</td>
<td>$\leq 0.01$</td>
<td>0.43</td>
<td>$\leq 7.9\cdot 10^{-3}$</td>
<td>$\leq 3.4\cdot 10^{-5}$</td>
</tr>
<tr>
<td>$^{214}\text{Bi} \ (\gamma)$</td>
<td>$\leq 0.0037$</td>
<td>0.33</td>
<td>$\leq 0.012$ *</td>
<td>$\leq 4.5\cdot 10^{-5}$</td>
</tr>
<tr>
<td>$^{214}\text{Bi} \ (\beta \text{ on } p+)$</td>
<td>$\leq 0.0098$</td>
<td>$&lt; 0.003$</td>
<td>0.21</td>
<td>$&lt; 5.2\cdot 10^{-6}$</td>
</tr>
<tr>
<td>$^{60}\text{Co} \ (\gamma)$</td>
<td>$\leq 4\cdot 10^{-4}$</td>
<td>0.02</td>
<td>0.066</td>
<td>$\leq 5.2\cdot 10^{-7}$</td>
</tr>
<tr>
<td>$^{60}\text{Co} \ (\gamma+\beta \text{ in Ge})$</td>
<td>$3\cdot 10^{-4}$</td>
<td>0.02</td>
<td>0.066</td>
<td>$4.0\cdot 10^{-7}$</td>
</tr>
<tr>
<td>$^{68}\text{Ga} \ (\gamma+\beta \text{ in Ge})$</td>
<td>$2.3\cdot 10^{-3}$</td>
<td>0.09</td>
<td>0.2</td>
<td>$4.1\cdot 10^{-5}$</td>
</tr>
<tr>
<td>Ra-chain $\alpha$ on p+</td>
<td>$\leq 0.8\cdot 10^{-3}$</td>
<td>$&lt; 0.003$</td>
<td>–</td>
<td>$&lt; 2.4\cdot 10^{-6}$</td>
</tr>
<tr>
<td>$^{42}\text{K} \ (\text{surface } \beta)$</td>
<td>several solutions under investigation</td>
<td></td>
<td>goal: $&lt; 3\cdot 10^{-4}$</td>
<td></td>
</tr>
</tbody>
</table>

PSD and veto combined acceptance of $0\nu\beta\beta$-decay events: 75% - 85% (depending on signal read-out noise performance)

* mean value for several different contributions
The GERDA Collaboration:

1. INFN Laboratori Nazionali del Gran Sasso, Assergi, Italy
2. Joint Institute for Nuclear Research, Dubna, Russia
3. Max-Planck-Institut für Kernphysik, Heidelberg, Germany
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14. Physik Institut der Universität Zürich, Switzerland
15. Physik Department E15, Technische Universität München, Germany

Other GERDA talks at DPG:

GERDA overview:
M. Heisel, HK 43.2, Tuesday 17:15
M. Agostini, T 103.1, Thursday 16:45

GERDA Phase I background:
N. Becerici-Schmidt, T 103.4, Thursday 17:40

GERDA Phase II K-42 background:
A. Lubashevskiy, HK66.7, Thursday 15:45

GERDA Phase II PSA:
A. Lazzaro, HK 66.6, Thursday 15:30
V. Wagner, T 110.2, Tuesday 17:05

GERDA Phase II detectors:
R. Falkenstein, T 110.1, Tuesday 16:45
B. Lehnert, T 110.3, Tuesday 17:20

GERDA Phase II LAr veto:
M. Walter, HK 46.8, Tuesday 18:30
Back-up
Backgrounds observed in Phase I:
- surface $\alpha$ from $^{226}$Ra chain
- surface $\beta$ from $^{42}$K (from $^{42}$Ar in LAr)
- $\gamma$ from Th and Ra decay chains

Additional bkg expected in Phase II:
- $\beta/\gamma$ decays of $^{60}$Co and $^{68}$Ga from cosmogenic activation of Ge

→ see talk by:
  N. Becerici-Schmidt, T 103.4, Do 17:40
Ramo’s theorem: 
\[ I(t) = q \cdot \nabla \phi_w(\vec{r}(t)) \cdot \vec{v} \]

- \( q, r, v \) – charge, position and velocity of charge cluster
- \( \phi_w \) – weighing potential

- ~95% volumetric efficiency of \( A/E \) position independence
- **separation sensitivity**: <10 ns (current peaks) \( \Rightarrow \) <1.2 mm (interactions; 1D)*
- \( I_{max}/E \) resolution \( \approx 0.6\% \) \( \Rightarrow \) ~15 keV sensitivity for 2nd interaction in a 2 MeV MSE

* using \( 12 \cdot 10^{-6} \) cm/s hole drift velocity [Bruyneel et al., NIM A 569 (2006) 764]
Pulse shape discrimination with BEGe

\[ I_{\text{max}} / E \Rightarrow \text{discrimination parameter} \]

\[ I_{\text{max}} \propto q \Rightarrow \]

**SSE**: single charge cluster:

\[ q \propto E \Rightarrow (I_{\text{max}} / E)_{\text{SSE}} \approx \text{const.} \]

**MSE**: several charge clusters:

\[ q_i < E \Rightarrow (I_{\text{max}} / E)_{\text{MSE}} < (I_{\text{max}} / E)_{\text{SSE}} \]

\[ E = \text{total event energy} \]
BEGe performance studies: Surface events

n+ electrode (≤ mm) → n+ surface pulses (NSP) occurrence

Irradiation with $^{90}$Sr and $^{106}$Ru β sources

Map of $I_{\text{max}}/E$

region of p+ contact pulses (PCP) occurrence

Scanning of p+ contact with $^{241}$Am α source and $^{90}$Sr β source

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Performance studies: $^{90}\text{Sr}$ and $^{106}\text{Ru}$ n+ surface $\beta$ events

$^{106}\text{Ru}$ survival fraction as a function of energy ($\beta$ and bremsstrahlung events)

Average = $8.2(6) \times 10^{-3}$

n+ surface $\beta$ event PSD rejection power demonstrated stable in region 1 - 2 MeV

NSP/MSE cut tuned to 90% survival of $0\nu\beta\beta$

MC cut set to 0.1% survival of $\beta$-like events and 20% survival of $\gamma$-like (bremsstrahlung) events.

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A over E distributions

Sr90 on the groove in LAr - A/E distribution
A over E distributions

Sr90 on the groove in LAr - A/E distribution
Performance studies: $^{241}$Am p+ contact α events

PCP cut tuned to 99% survival of $0\nu\beta\beta$

<table>
<thead>
<tr>
<th>surface</th>
<th>p+ contact</th>
<th>groove inner</th>
<th>groove bottom</th>
<th>groove outer</th>
</tr>
</thead>
<tbody>
<tr>
<td>survival fraction *</td>
<td>&lt; 1.1%</td>
<td>&lt; 12%</td>
<td>&lt; 1.0%</td>
<td>&lt; 1.2%</td>
</tr>
</tbody>
</table>

* 90% confidence-level upper limits
results limited by background in test setup; improved measurement analysis under way

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