A liquid argon scintillation veto for GERDA and LArGe

Part 1:
Veto concept
& LArGe measurements

Part 2:
light instrumentation
design options in GERDA

Mark Heisel for the GERDA Collaboration
DPG Göttingen, 2012
Germanium Detector Array

Clean room + lock system

Water tank

LAr cryostat

Ge detector array
Germanium Detector Array

Double beta decay:

\[ 2\nu\beta\beta: \quad ^{76}\text{Ge} \rightarrow ^{76}\text{Se} + 2\text{e}^- + 2\nu \]
\[ 0\nu\beta\beta: \quad ^{76}\text{Ge} \rightarrow ^{76}\text{Se} + 2\text{e}^- \]

Detector = Source

\[ \beta\beta\text{-energy spectrum:} \]

![Energy Spectrum](image)

fight background here at \( Q_{\beta\beta} = 2039 \text{ keV} \)
The GERDA background challenge

**Background index (BI)**

\[ \text{cts} / (\text{keV} \cdot \text{kg} \cdot \text{y}) \]

- present (Phase I): \( 1.7 \times 10^{-2} \)
- Phase II: \( 1.0 \times 10^{-3} \)

**Active background suppression:**

- water cherenkov muon veto
- detector anti-coincidence
- pulse shape discrimination (PSD)

**LAr veto:** detect argon scintillation light from background events that deposit energy in the LAr
Argon scintillation veto concept

Ar scintillation properties:
- 40,000 photons / MeV
- $\lambda = 128$ nm (XUV)
- singlet- & triplet component

Average scintillation pulse:
Examples for events in $Q_{\beta\beta}$:

$\beta\beta$-event $\rightarrow$ is not vetoed
Argon scintillation veto concept

Examples for events in $Q_{\beta\beta}$:

- $\beta\beta$-event $\rightarrow$ is not vetoed

- surface beta ($^{42}$K, $^{214}$Bi) $\rightarrow$ often not vetoed
Examples for events in $Q_{\beta\beta}$:

- **external** $(^{208}\text{Tl}, \ 2^{14}\text{Bi})$ → can be vetoed

- **$\beta\beta$-event** → is not vetoed

- **surface beta** $(^{42}\text{K}, \ 2^{14}\text{Bi})$ → often not vetoed
Examples for events in $Q_{\beta\beta}$:

- **external** $(^{208}\text{Tl}, ^{214}\text{Bi})$
  - → can be vetoed
- **$\beta\beta$-event**
  - → is not vetoed
- **surface beta** $(^{42}\text{K}, ^{214}\text{Bi})$
  - → often not vetoed
- **intrinsic cosm. bg (e.g. $^{60}\text{Co}$)**
  - → can be vetoed
LArGe test facility

- lock system
- 9x 8“ PMTs
- reflector foil & wavelength shifter
- bare Ge-detector
- cryostat with LAr volume 1000 l
- Shield (unfinished)
  Cu 15 cm, Pb 10 cm,
  Steel 23 cm, PE 20 cm

Location: Germanium detector lab LNGS @ 3800 m w.e.

128 nm

~450 nm

PMT
VM2000 + WLS

Ar scintillation
LArGe test facility
LArGe – suppression of internal $^{228}$Th

- detector: BEGe
- $^{228}$Th source
  - distance $\sim 7$ cm
- DAQ via FADC

Suppression factor at $Q_{\beta\beta} \pm 35$ keV:
- LAr veto $\sim 1200$
LArGe – suppression of internal $^{228}$Th

- detector: BEGe
- $^{228}$Th source distance ~7 cm
- DAQ via FADC

Suppression factors at $Q_{\beta\beta}$ ± 35 keV:
- LAr veto ~1200
- PSD ~2.4
- veto+PSD ~5200
LArGe – suppression of internal $^{228}\text{Th}$

- detector: BEGe
- $^{228}\text{Th}$ source distance ~7 cm
- DAQ via FADC

Left:
DEP ($^{208}\text{Tl}$) & 1621 keV ($^{212}\text{Bi}$)

Right:
2615 keV ($^{208}\text{Tl}$)
LArGe – suppression of internal $^{226}$Ra

- detector: BEGe
- $^{226}$Ra source
  - distance ~7 cm
- DAQ via FADC

Suppression factors at $Q_{\beta\beta} \pm 35$ keV:
- LAr veto ~4.6
- PSD ~4.1
- veto+PSD ~45
LArGe – summary of suppression factors

<table>
<thead>
<tr>
<th>source</th>
<th>position</th>
<th>LAr veto</th>
<th>PSD</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{60}$Co</td>
<td>int</td>
<td>$27 \pm 1.7$</td>
<td>$76 \pm 8.7$</td>
<td>$3900 \pm 1300$</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>ext</td>
<td>$3.2 \pm 0.2$</td>
<td>$4.4 \pm 0.4$</td>
<td>$18 \pm 3$</td>
</tr>
<tr>
<td></td>
<td>int</td>
<td>$4.6 \pm 0.2$</td>
<td>$4.1 \pm 0.2$</td>
<td>$45 \pm 5$</td>
</tr>
<tr>
<td>$^{228}$Th</td>
<td>ext</td>
<td>$25 \pm 1.2$</td>
<td>$2.8 \pm 0.1$</td>
<td>$129 \pm 15$</td>
</tr>
<tr>
<td></td>
<td>int</td>
<td>$1180 \pm 250$</td>
<td>$2.4 \pm 0.1$</td>
<td>$5200 \pm 1300$</td>
</tr>
</tbody>
</table>

Acceptance for $\beta\beta$-events:

- LAr veto: $>97\%$
- PSD: $90\%$

Combined suppression:

$$SF_{\text{total}} \sim 1.8 \times (SF_{\text{LAr}} \times SF_{\text{PSD}})$$
LArGe – background spectrum

- detector: GTF44 (not-enriched Ge)
- exposure: 116 kg·d
- shielding unfinished

- background index at $Q_{\beta\beta} \pm 150$ keV:
  $0.12 - 4.6 \cdot 10^{-2}$ cts / (keV·kg·y)
Part 2:

light instrumentation
design options for GERDA
PMT option vs. scintillation fibres

baseline design using PMTs

- copper shroud reflector foil + WLS $\varnothing = 500$ mm → wait for new lock
- low-background PMTs from top & bottom
- proven technology

scintillating fibres with SiPM readout

- scint. fibres $\varnothing = 250$ mm → fits present lock
- active LAr volume not confined
- more R&D

common features:

- no LAr drainage needed
- exchangeable
PMT option: hardware

low-background PMTs available:

- QE ~25%
- LAr teststand at MPIK

<table>
<thead>
<tr>
<th>PMT Type</th>
<th>Activity 228Th:</th>
<th>Activity 235U:</th>
<th>Activity 238U:</th>
</tr>
</thead>
<tbody>
<tr>
<td>R5912-02 MOD</td>
<td>165 mBq/PMT</td>
<td>374 mBq/PMT</td>
<td>1.0 mBq/PMT</td>
</tr>
<tr>
<td>R11065-10 MOD</td>
<td>1.0 mBq/PMT</td>
<td>&lt;0.94 mBq/PMT</td>
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</tbody>
</table>

voltage dividers
→ low-bg CuFlon-based

VM2000 reflector foil + wavelength shifter (TPB)

talk by A. Wegmann T113.7
Fibre design – hardware (1)

2 fibre types investigated

- BCF-10 blue scintillator no cladding
- BCF-91A green + WLS multiclad

► radiopurity

<table>
<thead>
<tr>
<th>γ-screening:</th>
<th>$^{228}$Th, $^{226}$Ra</th>
<th>&lt;16 mBq/kg</th>
<th>(BCF-91A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICPMS:</td>
<td>Th, U</td>
<td>&lt;0.06 mBq/kg</td>
<td>(both types)</td>
</tr>
</tbody>
</table>

► coupling: 9 fibres on 1 SiPM
► read-out both ends
► total: 10 strips á 27 fibres
Fibre design – hardware (2)

**KETEK SiPMs**
- sensitive surface 3x3 mm²
- 100 pieces available
  (~60 needed)
- summing ampl. in development:
  30 SiPM → 1 channel

**low-bg holder**
## Suppression factors & BI

### Monte Carlo for cylindrical active LAr volume $\varnothing = 600$ mm

<table>
<thead>
<tr>
<th>isotope</th>
<th>location</th>
<th>suppression factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100 keV</td>
</tr>
<tr>
<td>$^{208}$Tl</td>
<td>detector holders</td>
<td>254</td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>detector holders</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>detector surface</td>
<td>13.8</td>
</tr>
<tr>
<td>$^{42}$K</td>
<td>homogeneously in LAr</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>detector surface</td>
<td>1.3</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>homogeneously in Ge</td>
<td>57</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>detector surface</td>
<td>2.1</td>
</tr>
</tbody>
</table>

→ talk by N. Barros T109.5

### Instrumentation induced background index (preliminary)

<table>
<thead>
<tr>
<th></th>
<th>PMT option</th>
<th>fibre option (w/o self-veto)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no veto</td>
<td>self-veto</td>
</tr>
<tr>
<td>no veto</td>
<td>1.2</td>
<td>0.067</td>
</tr>
</tbody>
</table>
Conclusions & outlook
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Conclusions & outlook

- A LAr veto is a powerful tool for background rejection! (as demonstrated in LArGe)
- We are developing several design options for a LAr light instrumentation in GERDA!
- LAr bg-suppression may play a major role in GERDA Phase II