A liquid Argon scintillation veto for the GERDA experiment

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1 The GERDA experiment
2 Light instrumentation of GERDA
The GERDA experiment

Double beta decay

\[ ^{76}\text{Ge} \rightarrow ^{76}\text{Se} + 2e^- + 2\bar{\nu}_e \]

\[ ^{76}\text{Ge} \rightarrow ^{76}\text{Se} + 2e^- \]

Energy spectrum

\[ \tau_{1/2}^{2\nu} = (1.84^{+0.14}_{-0.08}) \times 10^{21} \text{ yr} \quad \text{arXiv:1212.3210} \]

\[ \tau_{1/2}^{0\nu} = 1.19 \times 10^{25} \text{ yr} \quad \text{Phys. Lett. B586,198 (2004)} \]

Main challenge

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

- Clean room + lock system
- Water tank
- LAr cryostat
- Detector array
Background rejection in GERDA

Sensitivity to the lower limit of the half life scale of $0\nu\beta\beta$ decay

$$T_{1/2} \propto \epsilon a \sqrt{\frac{Mt}{BI\Delta(E)}}$$

- $\epsilon$: detection efficiency
- $a$: abundance of $^{76}\text{Ge}$
- $Mt$: exposure [kg yr]
- $BI$: background index [cts/(keV kg yr)]
- $\Delta(E)$: energy resolution in ROI at $Q_{\beta\beta}$

**currently running:**

- **start:** November 2011
- **planned end:** summer 2013
- **detector mass:**
  - $M_{\text{coaxial}} = 17.7 \text{ kg}$
  - $M_{\text{BEGe}} = 3.6 \text{ kg}$
- **energy resolution @ 2.6 MeV:**
  - $\Delta E_{\text{coaxial}} \approx 4.5 \text{ keV}$
  - $\Delta E_{\text{BEGe}} \approx 3.0 \text{ keV}$
- **$BI \approx 2.4(3) \cdot 10^{-2} \text{ cts/(keV kg yr)}**

**Phase II**

- **additional 20 kg of enr Ge detectors (BEGe)**
- **cleaner and lighter detector holders, cables, ...**

**aspired $BI \leq 10^{-3} \text{ cts/(keV kg yr)}**

$\Rightarrow$ **active background suppression methods are needed** [T 109.4]

- detector anticoincidence
- water cherenkov veto
- pulse shape analysis [T 110.2, HK 66.6]

- **LAr scintillation veto** will be installed
LAr scintillation veto for background suppression

How does an active LAr veto work?

1. $0\nu\beta\beta$ event deposits its energy at one point in the Ge-crystal $\rightarrow$ not vetoed
2. Surface beta (Bi214, K42) $\rightarrow$ often not vetoed by LAr veto ($\rightarrow$ PSD)
3. $\gamma$ background events in ROI (Bi214, Tl208) $\rightarrow$ can be vetoed
   - energy deposition in multiple crystals $\rightarrow$ detector anticoincidence veto
   - Multisite event $\rightarrow$ pulse shape discrimination veto
   - energy deposition inside the crystal and in LAr $\Rightarrow$ create scintillation light $@ \lambda = 128\,\text{nm}$ $\Rightarrow$ can be used as anticoincidence veto
Experimental verification

energy spectrum for an internal Th228 source:

Suppression factors at $Q_{\beta\beta} \pm 35$ keV:

LAr $\approx 1200$; PSD $\approx 2.4$
LArGe - a test facility for GERDA
Monte Carlo validation & tuning of optical parameters

- simple geometry
- measurements available

Tuning of optical properties

- material reflectivities (Ge, Cu, VM2000, ...)
- absorption and emission spectra
- LAr attenuation length, light yield and triplet lifetime

- good MC description after tuning

<table>
<thead>
<tr>
<th>Bg</th>
<th>LArGe data internal</th>
<th>MC internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tl208</td>
<td>1180 ± 250</td>
<td>909 ± 235</td>
</tr>
<tr>
<td>Bi214</td>
<td>4.6 ± 0.2</td>
<td>3.8 ± 0.1</td>
</tr>
<tr>
<td>Co60</td>
<td>27 ± 2</td>
<td>16.1 ± 1.3</td>
</tr>
</tbody>
</table>

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<tr>
<th>Bg</th>
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<th>MC external</th>
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<tr>
<td>Tl208</td>
<td>25 ± 1.2</td>
<td>17.2 ± 1.6</td>
</tr>
<tr>
<td>Bi214</td>
<td>3.2 ± 0.2</td>
<td>3.2 ± 0.4</td>
</tr>
</tbody>
</table>
Light instrumentation for GERDA

“Hybrid” LAr veto design

- result of MC simulation optimization campaign
- uses combination of PMTs and scintillation fibers to read-out the scintillation light [T109.2]

Requirements on light instrumentation

- big instrumented volume
- low instrumentation induced background index
  - Photomultiplier
  - Wavelength shifting fibers
  - wavelength shifting and reflective foil
- applicable without LAr drainage
“Hybrid” LAr veto design

Photomultiplier
- type: 3 " R 11065-10/-20
- 9* top, 7* bottom

Scintillating fibers [T 109.2]
- build the middle shroud
- type: BCF-91A coated with TPB
- light readout at upper end by SiPMs

Copper shroud + reflective foil
- Tetratex coated with TPB [HK 46.8]
- installed on inner side of copper shrouds
Photomultiplier - Hardware

screening results [mBq/pc]

<table>
<thead>
<tr>
<th></th>
<th>Th228</th>
<th>Ra226</th>
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<tbody>
<tr>
<td>PMT</td>
<td>&lt; 1.94</td>
<td>&lt; 1.7</td>
</tr>
<tr>
<td>VD</td>
<td>&lt; 0.5</td>
<td>&lt; 1.14</td>
</tr>
</tbody>
</table>

* calculated from component screening currently screening of 6 R11065-10 PMTs

R11065-20 has higher QE than R11065-10

peak-to-valley:

- test of up to 10 PMTs in LAr
- light yield measurements
- gain measurements
“Hybrid” LAr veto design - MC simulations

Tl208 in holders:

Bi214 in holders:

suppression factors

<table>
<thead>
<tr>
<th>Holders</th>
<th>Surface</th>
<th>Homogenous</th>
<th>External</th>
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</thead>
<tbody>
<tr>
<td>Bi214</td>
<td>10.3 ± 0.3</td>
<td>3.5 ± 0.1</td>
<td>54.8 ± 7.9</td>
</tr>
<tr>
<td>Tl208</td>
<td>320 ± 34</td>
<td>-</td>
<td>-</td>
</tr>
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</table>
“Hybrid” LAr veto design - MC simulations

Systematics studies

- changed attenuation for XUV light and metal reflectivities dramatically

<table>
<thead>
<tr>
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<th>Baseline</th>
<th>Attenuation * 0.2</th>
<th>Reflectivity * 0.1</th>
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<tbody>
<tr>
<td>Bi214 in holders</td>
<td>10.3 ± 0.3</td>
<td>8.9 ± 0.3</td>
<td>9.4 ± 0.3</td>
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</table>

⇒ LAr veto gives still good suppression factors but p.e. yield drops
“Hybrid” LAr veto design

Instrumentation induced BI $[\text{cts/}(\text{keV kg yr})]$
Installation of LAr scintillation veto is planned for Phase II of GERDA

Hybrid design using scintillating fibers and PMTs is the baseline option

- hardware tests are ongoing
- construction has started

Extensive MC simulation campaign performed

- used LArGe for validation and tuning
- provided optimizations to the hardware design

LAr veto suppression factors look promising:

- $> 10^2$ for Th$^{228}$ ($\approx 300$ close by, $\approx 100$ far from detectors)
- $\approx 10$ for nearby Ra$^{226}$ background source

Instrumentation induced BI within the budget
Thanks for your attention!
Veto efficiencies for different background sources are estimated by Monte Carlo simulations

- MaGe (Geant4) based simulation of nuclear decays
- If event passes cuts on energy deposition in the Ge crystals, optical photons created in the LAr are propagated. Otherwise event is discarded
  - photons are tracked inside the wls fiber
  - green shifted photons in the fiber can reach the PMTs
- reflectivity and surface roughness of the surrounding materials are implemented