A liquid argon scintillation veto for GERDA and LArGe

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2\(\beta\) decay

\((A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{v}_e\)

allowed and observed

\[
\left( T^{0\nu}_{1/2} \right)^{-1} = F^{0\nu} \cdot \left| M^{0\nu} \right|^2 \cdot m_{\beta\beta}^2
\]

\[
\langle m_{\beta\beta} \rangle = \left| \sum_i U_{ei}^2 m_{\nu i} \right|
\]

\((A,Z) \rightarrow (A,Z+2) + 2e^-\)

violates lepton number conservation

\(M^{0\nu}\) - nuclear matrix element

\(F^{0\nu}\) - phase space integral

depends on the Q value

\(\langle m_{\beta\beta} \rangle\) - effective neutrino mass
For a better limit we need:
- more mass
- lower background
- better energy resolution
- measure longer ??

\[ T_{1/2}^{0\nu} \sim \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} [y] \]

- \( M \) - mass of the isotope
- \( t \) - time
- \( B \) - background
- \( \Delta E \) - resolution

Claim


See talks: HK 40. 2-6
GERDA

See talks: HK 40. 2-6
LAr veto - The concept

In the Region of Interest around 2040 keV

- Nearby $^{208}\text{Tl}$ events can be easily vetoed with very high efficiency

- $^{214}\text{Bi}$ is less effective

- Does not work for surface $\alpha$ and $\beta$ events

- Veto efficiency in GERDA will strongly depend on the origin of the background

Tuesday, April 3, 2012
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.


- PMT
- VM2000 + WLS
- Ar scintillation

~450 nm
128 nm
LArGe test facility
LArGe, Suppression of internal $^{228}\text{Th}$

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

**Suppression factors at $Q_{\beta\beta} \pm 35$ keV:**
- LAr veto: $\sim 1200$
- PSD: $\sim 2.4$
- veto+PSD: $\sim 5200$

Ref: Taup proc.
LArGe, Suppression of internal $^{228}$Th

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

Left:
- DEP ($^{208}$TI)
- 1621 keV ($^{212}$Bi)

Right:
- 2615 keV ($^{208}$TI)
**LArGe, Suppression of internal $^{226}\text{Ra}$**

- **detector**: BEGe
- **$^{226}\text{Ra}$ source distance**: $\sim 7$ cm
- **DAQ via FADC**

**Suppression factors** at $Q_{\beta\beta} \pm 35$ keV:
- LAr veto $\sim 4.6$
- PSD $\sim 4.1$
- veto+PSD $\sim 45$
LArGe, Background spectrum

- detector: GTF44 (non-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)
### Summary of suppression factors

<table>
<thead>
<tr>
<th>source</th>
<th>position</th>
<th>suppression factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LAr veto</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>int</td>
<td>27 ± 1.7</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>ext</td>
<td>3.2 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>int</td>
<td>4.6 ± 0.2</td>
</tr>
<tr>
<td>$^{228}$Th</td>
<td>ext</td>
<td>25 ± 1.2</td>
</tr>
<tr>
<td></td>
<td>int</td>
<td>1180 ± 250</td>
</tr>
</tbody>
</table>

#### Acceptance for $\beta\beta$-events:
- LAr veto: >97%
- PSD: 90%

#### Combined suppression:

$$SF_{\text{total}} \approx 1.8 \times (SF_{\text{LAr}} \times SF_{\text{PSD}})$$

Options for GERDA

Design with PMTs

- Copper shroud reflector foil + WLS Ø = 500 mm → wait for new lock
- Low-background PMTs from top & bottom
- Proven technology

Common features:

- No LAr drainage needed
- Exchangeable

Scintillating fibres with SiPM readout

- Closed cylinder made of fibres Ø = 250 mm → fits present lock
- Active LAr volume not confined
- The least invasive solution

Tuesday, April 3, 2012
PMT option - hardware

low-background PMTs available:

- QE ~25%
- LAr teststand at MPIK

<table>
<thead>
<tr>
<th></th>
<th>R5912-02 MOD (8-inch)</th>
<th>R11065-10 MOD (3-inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{228}$Th:</td>
<td>165 mBq/PMT</td>
<td>1.0 mBq/PMT</td>
</tr>
<tr>
<td>$^{238}$U:</td>
<td>374 mBq/PMT</td>
<td>&lt;0.94 mBq/PMT</td>
</tr>
</tbody>
</table>

h = 210 cm
Ø = 50 cm

voltage dividers
→ low-bg CuFlon-based

VM2000 reflector foil + wavelength shifter (TPB)
Wavelength shifter - Basic Idea

TPB

128 nm (VUV) → 430 nm

Detected with PMT

Collected with WLS fiber

Emitted

Inefficient (~50%), but it works

WLS Fiber coated with TPB
SiPM + WLS fiber design

- Idea was tested at small scale
- SiPMs work at cryogenic temperatures
- TPB + WLS fiber concept works

SiPMs

* Ketek GmbH Munich based company. Willing to sell SiPMs in ‘die’.

* Purchased 100 pieces. Already delivered. (~60 needed)

http://indico.cern.ch/getFile.py/access?contribId=23&sessionId=3&resId=0&materialId=slides&confId=117424
SiPM holder

- SiPM delivered in ‘die’, low background packaging is developed
- 9 fiber coupled to 1 SiPM
- units of 27 fibers = 38 mm x 2, full coverage = 10 strips, manageable quantity
# Induced background

**ICPMS results: WLS fiber measured at LNGS**

<table>
<thead>
<tr>
<th>Element</th>
<th>Conc.</th>
<th>Activity Bq/kg</th>
<th>Background cts / (keV kg Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>15 ppb</td>
<td>$4.6 \times 10^{-4}$</td>
<td>-</td>
</tr>
<tr>
<td>Th</td>
<td>14.3 ppt</td>
<td>$5.8 \times 10^{-5}$</td>
<td>$8 \times 10^{-4}$</td>
</tr>
<tr>
<td>U</td>
<td>3.4 ppt</td>
<td>$4.2 \times 10^{-5}$</td>
<td>$7.9 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

- The whole setup consists of about 0.5 kg fiber (2 m$^2$ photon detector)
- Relevant activity: $O(\sim 10 \, \mu\text{Bq})$
- Compatible with the background goal of GERDA Phase II
Expected Suppression Factors

- Fibers are sensitive also on the outer side \((E_{\text{inside}} + \Omega E_{\text{outside}}) > E_{\text{eff.thr}}\).
- Nearby source: Simulated in the copper holder of the Ge detectors
- External source single gamma (2.6 MeV) hitting the array
- At least 10x suppression expected

<table>
<thead>
<tr>
<th>Threshold keV</th>
<th>Internal TL208</th>
<th>external TL208</th>
<th>TL208 in fiber</th>
<th>Bi214 in fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>40.7</td>
<td>61.6</td>
<td>4863</td>
<td>12.0</td>
</tr>
<tr>
<td>100</td>
<td>13.0</td>
<td>11.2</td>
<td>503</td>
<td>4.1</td>
</tr>
<tr>
<td>130</td>
<td>10.0</td>
<td>7.6</td>
<td>286</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Suppression factors for different thresholds, only energy deposited in LAr, no delayed coincidence
Summary - Outlook

- Significant reduction of the background was demonstrated
- LAr instrumentation will be implemented in GERDA
- Two competing concepts are being developed
- To be deployed in Phase II