MC BENCHMARKS FOR LAR INSTRUMENTATION IN GERDA

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on behalf of the GERDA collaboration

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Germanium Detector Array

Detector design

- Clean room.
- Lock system.
- Water tank (steel).
- Muon veto (Čerenkov).
- Cryostat (steel + Cu).
- Liquid Argon.
- Detector array.
• Instrument the LAr to detect scintillation light.
  – Veto backgrounds from coincidence between Ge and LAr events.
  – Principle already demonstrated in test facility (LArGe).
  – Efficiency dependent of type of background.
  – Aim implementation for GERDA phase II.

• Two major instrumentation designs (M. Heisel, T 116.1).
  – Optical fiber design.
  – PMT design.

Goals for the MC:
• Estimate background suppression (veto efficiency) of the design.
• Optimize the design to maximize background suppression.
LAr as an active veto

- Detect scintillation light in LAr to tag external background events.
- Very high light yield: $\sim 4 \times 10^4$ photons/MeV.
- Single re-emission peak ($\lambda = 128$ nm).
  - Not directly detectable.
  - Use wavelength shifter (eg. VM2000).
- Some challenges:
  - Properties strongly affected by impurities (eg.: Xe, N$_2$).
  - Short scattering length in emission range ($\sigma_{128nm} \approx 80$ cm).
- Some advantages:
  - Very distinctive short and long decay times ($\tau_{short} \sim 6$ ns, $\tau_{long} \sim 1200 - 1500$ ns).
  - Transparent in the visible range ($\sigma_{550nm} > 1$ km).

Types of studied backgrounds

- **Internal backgrounds:**
  - Mostly cosmic activations ($^{60}\text{Co}$).

- **Backgrounds in LAr:**
  - Backgrounds distributed in LAr ($^{214}\text{Bi}$, $^{42}\text{K}$).
  - Backgrounds on the surface of crystals (mostly $\alpha$ : $^{210}\text{Po}$).

- **Bulk contamination of support structures:**
  - $^{208}\text{Tl}$ ($^{232}\text{Th}$ chain), $^{214}\text{Bi}$ ($^{226}\text{Ra}$).

- **Only background events that deposit** $Q_{\beta\beta} \pm 50\text{keV}$ in Ge **are relevant.**

- Different veto energy thresholds are tested.

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**Information for all simulated sources:**

- Suppression factor $S_{\text{eff}} = \frac{N_{\text{Ge}}}{N_{\text{Genv}}}.$

- The estimated energy threshold of LAr readout in LArGe is $\sim 100$ keV.
Validation of the MC

- Several measurements with calibration sources performed in LArGe (M. Heisel, T 116.1).
  - Using both internal and external sources.
  - A single BEGe as the Germanium detector (T 116.4).
- Use these measurements as a base to validate the MC.
  - No measurements with GERDA and LAr veto.
  - Simpler geometry.
  - Smaller scale (LAr volume).
- Tune the MC (e.g.: optical properties of Argon).
Validation of the MC Results with LArGe

**228Th:**
- Only $^{208}$Tl was simulated (major contributor).
- Some results:
  Rate of backgrounds in $Q_{\beta\beta}$: 0.078 % w.r.t. simulated events.
  - $S_{100\text{keV}}$: 1507
  - $S_{20\text{keV}}$: 2748
  - $S_{\text{measured}}$: 1180 ± 250

**226Ra:**
- Only $^{214}$Bi was simulated.
- Results:
  Rate of backgrounds in $Q_{\beta\beta}$: $7 \times 10^{-3}$ % w.r.t. simulated events.
  - $S_{100\text{keV}}$: 5.6
  - $S_{20\text{keV}}$: 8.1
  - $S_{\text{measured}}$: 4.6 ± 0.2
**Validation of the MC Results with LArGe**

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### **60Co:**

- Activation from cosmic rays.
- Some results:
  
  Rate of backgrounds in $Q_{\beta\beta}$:
  
  $$2.93 \times 10^{-3} \%.$$  

  - $S_{100\text{keV}}$: 55  
  - $S_{20\text{keV}}$: 73  
  - $S_{\text{measured}}$: 27 ± 1.7.

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### Summary of LArGe MC tests:

- MC consistent with the experimental measurements.
  - The MC is not yet fully tuned.
- Discrepancy in $^{60}\text{Co}$ simulation likely due to imprecise information:
  - Position of the source.
  - Design of the BEGe.
  - Design of the source.
  - Geometrical effects (shadows).
• Principle similar to LArGe.
• Considerably more complex geometry.
  – Multiple Ge detectors instead of a single one.
  – Additional detector components (holders, cables).
• Simulations of major backgrounds estimated through the deposited energy:
  – These tests do not yet allow to properly compare designs.
  – It serves as an indication of the best possible scenario for the veto.
Bulk contamination ($^{208}\text{Tl}$ on crystal holders)

- $S_{100\text{keV}} : 254$
- $S_{10\text{keV}} : 354$

- High efficiency due to multiple $\gamma$.
Bulk contamination \( ^{214}\text{Bi on crystal holders} \)

Energy spectra for different veto energy thresholds \( ^{214}\text{Bi} \)

\[ S_{100\text{keV}} : 3.5 \]
\[ S_{10\text{keV}} : 4.4 \]

- Single \( \gamma \) lowers veto efficiency.
MC Status for GERDA Phase-I
Homogeneous distribution of $^{42}$K in LAr

- $S_{100\,\text{keV}} : 6.0$
- $S_{10\,\text{keV}} : 54.8$

- Major background visible in GERDA.
- Distribution known to be not homogeneous.
MC Status for GERDA Phase-I

Bulk contamination ($^{42}$K on crystal surface)

Veto Efficiencies $K_{42\_surf}$

- $S_{100\,keV} : 1.3$
- $S_{10\,keV} : 1.4$

- Major background visible in GERDA.
- Distribution known to be not homogeneous.
## Summary of results so far

<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>$^{280}$Tl</td>
<td>Holders</td>
<td>254</td>
</tr>
<tr>
<td>$^{214}$Bi</td>
<td>Holders</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Crystal surface</td>
<td>13.8</td>
</tr>
<tr>
<td>$^{42}$K</td>
<td>Homogeneous in LAr</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Surface of Crystal</td>
<td>1.3</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>Homogeneously in Crystals</td>
<td>57</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>Surface of Crystal</td>
<td>2.1</td>
</tr>
</tbody>
</table>

- Values serve as an optimistic indicator of efficiency.
• Currently MC for LAr veto designs is an ongoing project.
• MC being tuned using LArGe results as base.
  – Initial results are already promising.
• LAr veto instrumentation able to reduce background index by 2 orders of magnitude (on specific backgrounds).
  – Limited efficiency on most visible GERDA background ($^{42}$K).
  – Different approaches being followed in this case.
  – Will become a key component to achieve the background index aimed for phase II ($10^{-3}$ counts/(kg·yr·keV)).
  – Present background index: $\sim 10^{-2}$ counts/(kg·yr·keV).
• LAr veto geometries finishing implementation.
• Further validations with LArGe source measurements undergoing.
• More complex background studies under preparation.
  – Inhomogeneous distributions.