BACKGROUND REDUCTION FOR GERMANIUM DOUBLE BETA DECAY DETECTORS

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GERDA Collaboration Meeting. Ringberg Castle. 12-14 Feb 2006
OUTLINE

- Motivations.
- Simulation features.
- Granularity.
- Segmentation.
- Spatial Resolution & Pulse Shape Analysis.
- Estimation of counting rates.
- $0\nu\beta\beta$ Events.
- Summary & Conclusions.
- Outlook.
MOTIVATIONS

- New generation of **neutrinoless double beta decay** experiments using enriched germanium detectors need to reach a background level of \( \sim 10^{-3} \text{ c/(keV kg y)} \) in the Region of Interest to have the expected sensitivity.

- Three main contributions in 2.0-2.1 MeV region:
  - Internal contamination of \( ^{60}\text{Co} \) and \( ^{68}\text{Ge} \) due to cosmogenic activation of germanium crystals.
  - External **2614.5 keV** gammas coming from \( ^{232}\text{Th} \) chain.

- Need to study the optimal configuration for the mass and the distribution of the germanium detectors and to quantify the background reduction that can be reached using different techniques:
  - Granularity of the experiment.
  - Segmentation of the crystal.
  - Pulse Shape Analysis (PSA).

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Cylindrical detectors (D=h).
Natural Germanium.
Masses between 0.1 and 4 kg.
Neither cryostat nor shielding.
Standard GEANT4 models.

Position, Energy and Time of each interaction produced in an event have been registered.

Possibility of different analysis.
What could be the optimal mass of the detectors that build the whole experiment to have a background level as low as possible?

28% more events registered in the RoI in a 4 kg detector than in a 2 kg one for $^{60}$Co internal contamination.

1.58 c/kev/10$^4$ decays
What could be the optimal mass of the detectors that build the whole experiment to have a background level as low as possible?

26% more events registered in the RoI in a 4 kg detector than in a 2 kg one for $^{68}\text{Ge}$ internal contamination.

$2.26 \text{ c/kev/10}^4\text{decays}$
What could be the optimal mass of the detectors that build the whole experiment to have a background level as low as possible?

54% less events registered in the RoI in a 4 kg detector than in a 2 kg one for 2614.5 keV external photons.

**Optimal Mass of the Component Detectors Depends on What Kind of Background Events We Want to Reduce.**
How much can we reduce the background by segmentation of crystals and anticoincidence techniques?

SEGMENTATION SCHEME:
Up to 98 out of 100 background events coming from $^{60}$Co internal contamination can be rejected applying segmentation and anticoincidence techniques.

95 out of 100 events from $^{68}$Ge and more than a half from 2614.5 keV gammas can be also rejected.
### Summary for Other Segmentation Schemes

Percentage of rejected events in 2-2.1 MeV region by segmentation and anticoincidence techniques.

<table>
<thead>
<tr>
<th></th>
<th>2 kg</th>
<th></th>
<th>4 kg</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 kg</td>
<td></td>
<td>4 kg</td>
<td></td>
</tr>
<tr>
<td>7 planes</td>
<td>7 planes &amp; 6 sectors</td>
<td>9 planes &amp; 6 sectors</td>
<td>9 planes &amp; 11 planes &amp; 6 sectors</td>
<td>11 planes &amp; 6 sectors</td>
</tr>
<tr>
<td>9 planes</td>
<td>7 planes &amp; 6 sectors</td>
<td>9 planes &amp; 6 sectors</td>
<td>9 planes &amp; 11 planes &amp; 6 sectors</td>
<td>11 planes &amp; 6 sectors</td>
</tr>
<tr>
<td>68 Ge</td>
<td>92.4</td>
<td>95.6</td>
<td>97.0</td>
<td>98.2</td>
</tr>
<tr>
<td>60 Co</td>
<td>86.1</td>
<td>90.7</td>
<td>93.2</td>
<td>95.1</td>
</tr>
<tr>
<td>2614.5 keV γ</td>
<td>40.6</td>
<td>44.4</td>
<td>48.6</td>
<td>51.0</td>
</tr>
</tbody>
</table>

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Spatial resolution of the detectors, obtained by the analysis of the registered pulses, allows to differentiate background “multisite” events from real DBD “monosite” events.

Current techniques can locate an energy deposit with an accuracy between 2.5 and 5.4 mm. (Kröll, Bazzacco. NIM A 565 (2006) 691-703)

- 4 kg Detector:

0.1% of background events coming from $^{60}$Co internal contamination are “monosite” if a 3 mm spatial resolution is assumed.

The value is 0.5% if the spatial resolution is 5 mm.
Spatial resolution of the detectors, obtained by the analysis of the registered pulses, allows to differentiate background “multisite” events from real DBD “monosite” events.

Current techniques can locate an energy deposit with an accuracy between 2.5 and 5.4 mm. (Kröll, Bazzacco. NIM A 565 (2006) 691-703)

The distribution is quite different for the external 2614.5 keV contamination.

3 mm. $\rightarrow$ 39.7% “monosite”.
5 mm. $\rightarrow$ 45.5% “monosite”.

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| Percentage of “monosite” events in 2-2.1 MeV region assuming different spatial resolutions. |
|--------------------------------------------------|--------------------------------------------------|
| 2 kg                                             | 4 kg                                             |
| 3 mm resolution                                  | 5 mm resolution                                  |
| $^{60}\text{Co}$                                 | $^{68}\text{Ge}$                                 |
| 0.3                                               | 1.1                                              |
| 1.0                                               | 3.0                                              |
| 0.1                                               | 0.8                                              |
| 0.5                                               | 2.2                                              |
| 44.4                                              | 48.8                                             |
| 39.7                                              | 45.5                                             |

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COUNTING RATES

➢ To estimate the raw background is necessary to make some hypothesis:

➢ COSMOGENIC ACTIVATION OF THE CRYSTAL:

➢ $^{60}$Co: 5 kg$^{-1}$ d$^{-1}$ of Production Rate and 30 d of Exposure Time.

➢ $^{68}$Ge: 2 configurations

a) 1 kg$^{-1}$ d$^{-1}$ of Production Rate, 180 d of Exposure Time and 180 d of Cooling Time.

b) 10 kg$^{-1}$ d$^{-1}$ of Production Rate, 180 d of Exposure Time and 730 d of Cooling Time.

➢ EXTERNAL CONTAMINATION:

➢ Environmental flux of 2614.5 keV photons: $0.1 \text{ cm}^{-2} \text{ s}^{-1}$ (based on LSC meas.).

➢ INTRINSIC CONTAMINATION OF LEAD:

➢ $^{232}$Th Activity: 1 $\mu$Bq kg$^{-1}$ (as starting value).
## COUNTING RATES

Estimates of counting rates $R$ (c keV$^{-1}$ kg$^{-1}$ y$^{-1}$) in the 2-2.1 MeV region of interest

<table>
<thead>
<tr>
<th></th>
<th>2 kg</th>
<th>4 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>raw</td>
<td>9 planes &amp; 6 sectors</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>2.9x10^{-3}</td>
<td>5.2x10^{-5}</td>
</tr>
<tr>
<td>$^{68}$Ge (a)</td>
<td>1.2x10^{-2}</td>
<td>6.1x10^{-4}</td>
</tr>
<tr>
<td>$^{68}$Ge (b)</td>
<td>3.1x10^{-2}</td>
<td>1.5x10^{-3}</td>
</tr>
<tr>
<td>External</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2614.5$ keV</td>
<td>3.0x10^{-2}</td>
<td>1.5x10^{-2}</td>
</tr>
<tr>
<td>$30$ cm Pb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2614.5$ keV</td>
<td>2.6x10^{-4}</td>
<td>1.3x10^{-4}</td>
</tr>
<tr>
<td>$40$ cm Pb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intrinsic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2614.5$ keV</td>
<td>2.8x10^{-3}</td>
<td>1.4x10^{-3}</td>
</tr>
<tr>
<td>in lead</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BEST TOTAL</strong></td>
<td>1.8x10^{-2}</td>
<td>2.1x10^{-3}</td>
</tr>
</tbody>
</table>

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A “single” energy deposit of 2040 keV is expected as $0\nu\beta\beta$ signal.

There are cases where not all the energy is collected.
How many $\nu\beta\beta$ events can we lose due to Bremmstrahlung?

- Simulation of 2 electrons from the same point:
  \[(x_0, y_0, z_0, E_1, E_2, \phi)\]
  
  Random angle is good to obtain a first estimation.

  \[E_1 + E_2 = 2040 \text{ keV}\]

\[E_1 = E_2 = 1020 \text{ keV}.\]
$0\nu\beta\beta$ EVENTS

Distribution of the maximum distance between hits of an event is interesting for further analysis.

Most of the events have a maximum “interdistance” below 5 mm.

MONOSITE EVENTS FOR PSA.
# 0νββ EVENTS

## DETECTION EFFICIENCY OF 0νββ EVENTS IN A 4 kg DETECTOR

<table>
<thead>
<tr>
<th>Full Crystal</th>
<th>Segmentation</th>
<th>PSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 planes</td>
<td>11 planes</td>
<td>3 mm</td>
</tr>
<tr>
<td>9 planes</td>
<td>11 planes</td>
<td>3 mm</td>
</tr>
<tr>
<td>11 planes</td>
<td>6 sectors</td>
<td>3 mm</td>
</tr>
<tr>
<td>11 planes</td>
<td>6 sectors</td>
<td>3 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Detection Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 1020 keV</td>
<td>94.66</td>
</tr>
<tr>
<td>Rand. Dir.</td>
<td></td>
</tr>
<tr>
<td>1500 + 540 keV</td>
<td>93.91</td>
</tr>
<tr>
<td>Rand. Dir.</td>
<td></td>
</tr>
<tr>
<td>1734 + 306 keV</td>
<td>92.85</td>
</tr>
<tr>
<td>Rand. Dir.</td>
<td></td>
</tr>
<tr>
<td>2040 keV</td>
<td>90.91</td>
</tr>
<tr>
<td>Rand. Dir.</td>
<td></td>
</tr>
</tbody>
</table>

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$\nu\beta\beta$ EVENTS

**DBD Events Detection Efficiency**

- **Full Crystal**
- **Segmented Crystal: 11 planes by 6 sectors**
- **PSA: 5mm Spatial Resolution**
- **PSA: 3mm Spatial Resolution**

$\epsilon = aE^2 + bE + c$

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The importance of the efficiency.

Mt vs Efficiency

PSA: 3 mm. 66 kg y more.

Full Crystal

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A particular case: **Border events**

Anticoincidence between segments rejects these events.

PSA considers these events as **MONOSITE**
Final background level of $10^{-3}$ counts·keV⁻¹·kg⁻¹·y⁻¹ using 2 kg or 4 kg detectors:

- Combination of some background reduction techniques.
- Appropriate contamination levels in the used components.

Massive detectors are better in order to reject background events coming from external sources but worse for internal one.

Background events coming from internal contamination of the crystal can be mostly rejected applying PSA and segmentation techniques.

All these techniques have to be applied optimizing the efficiency of 0νββ events detection.
It’s necessary to find ways to have a raw background level as low as possible:

- Crystal growth and storage underground in order to avoid cosmogenic activation.
- Use of radiopure materials for the cryostat and build the shielding.

All the techniques to reduce the background level are quite conventional and can be done right now.
OUTLOOK

- Study of other background sources (neutrons…).
- Estimation of a final value of the efficiency for $0\nu\beta\beta$ events detection.
- Development of a PSA system.
- Design and development of a natural germanium prototype to be installed at Canfranc Underground Laboratory.
  - Underground electroformed copper cryostat.
  - Segmentation configuration.
  - Acquisition system.
- Design and construction of the shielding for the prototype.
- Materials selection.
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