α-Background characterization for the GERDA experiment

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Outline:

- Motivation.
- GERDA Phase-I data.
- Analysis of α-background.
- Implications of α-background.
- Summary.

Motivation

GERDA experiment is searching for neutrinoless double beta ($0\nu\beta\beta$) decay of ^{76}Ge, using an array of HPGe detectors enriched in ^{76}Ge isotope.

limit: $T^{0\nu}_{1/2}(^{76}\mathrm{Ge}) > 1.9 \cdot 10^{25}$ y (90% C.L.) from HdM Collaboration [Eur. Phys. J. A 12, 147154 (2001)]

claim: $T^{0\nu}_{1/2}(^{76}\mathrm{Ge}) = 1.19 \cdot 10^{25}$ y [Phys. Lett. B 586 (2004) 198-212]

To achieve a higher sensitivity on the $T_{1/2}$:

$\Rightarrow$ **Increase the exposure**
M (mass of Ge) $\times$ t (measuring time)

$\Rightarrow$ **Lower the background index**
BI: number of events in ROI ($Q_{\beta\beta} \pm \Delta E$) per 1 kg Germanium, per 1 year of measuring time, per 1 keV energy window

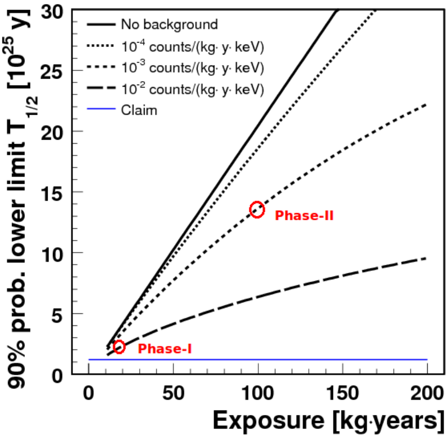
GERDA Phase-I: Test the claim

GERDA Phase-II: Improve sensitivity on $T_{1/2}$

▷ Increased exposure

▷ An order-of-magnitude lower BI

Understanding of the background is of major importance to suppress it and to further mitigate it for GERDA Phase-II.

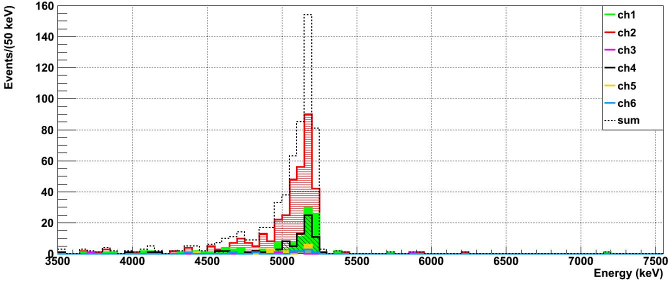


[Caldwell,Kröninger;Phys. Rev. D74, 092003 (2006)]

GERDA Phase-I data

High-energy region of the GERDA background spectrum

Measured background spectrum of enriched detectors (ch1-ch6) in Phase-I.
Measuring time: 9 Nov 2011 - 9 Feb 2012. Total exposure: 3.52 kg·y



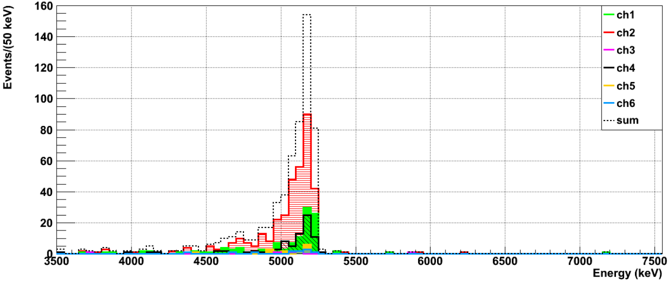
High-energy (E $>$ 3.5 MeV) events $\rightarrow$ α-candidates:

Not muons; show energy in single detector; energy above γ, β bg from natural radioactivity.

Quantify background contribution from degraded α's in the ROI, i.e., around $Q_{\beta\beta}$=2.039 MeV.

$\Rightarrow$ Find a model that describes the data

Measured background spectrum of enriched detectors (ch1-ch6) in Phase-I.
Measuring time: 9 Nov 2011 - 9 Feb 2012. Total exposure: 3.52 kg·y



▷ **Peak around 5.2 MeV**

• α-events at detector surfaces are subject to energy loss and straggling in the dead layers (contacts at the surface of the detectors)

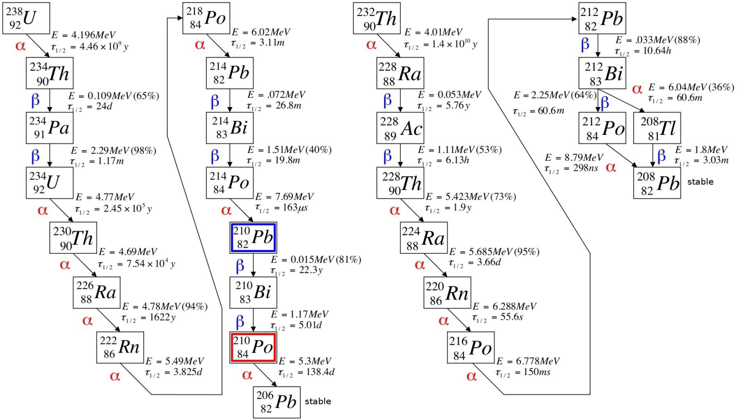
⇒ **result in a peak structure**

• α-events originate in materials external to the detector result in a broad continuum of events.

▷ **Counting rates differ from detector to detector** ⇒ detector contamination

Model: ^{210}Pb surface contamination

^{222}Rn-decays at detector surfaces during an exposure to air → implantation of ^{222}Rn-daughters
^{210}Pb implanted into the surface ($T_{1/2} = 22$ y) → steady supply of ^{210}Po α-decays (E=5.3 MeV)

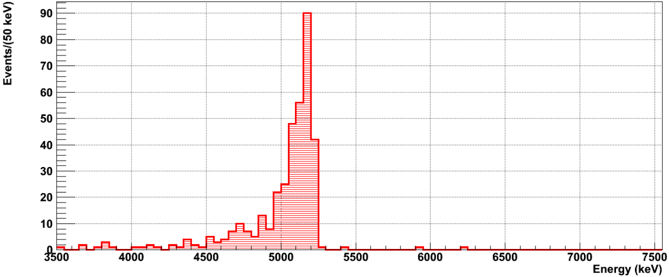


^{210}Pb surface contamination ⇒ expect 5.3 MeV alphas from ^{210}Po at a constant rate (degraded spectrum at the dead layer)

Analysis of α-background

Start with the detector that shows the highest counting rate at high-energy region: **ch2**

Measured background spectrum of **ch2** *in Phase-I.*
Measuring time: 9 Nov 2011 - 9 Feb 2012. Total exposure: 0.58 kg·y

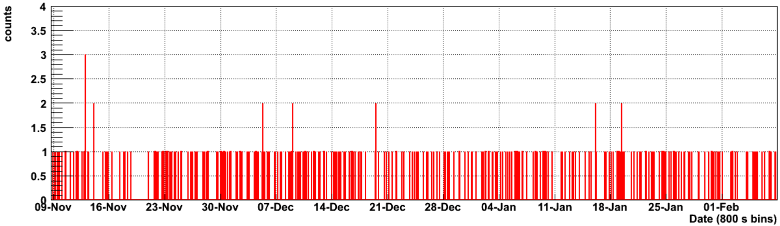


Assumption: Majority of high-energy events come from ^{210}Po α-decays (E = 5.3 MeV) at the surface, due to an initial ^{210}Pb contamination.

- Expect: Poisson process with a constant rate of R = 4.2 events/day
- Reproduce the energy spectrum with a dedicated MC simulation

Analysis of α-background

Counting rate of high-energy events from **ch2** *in dt=800 second time intervals. Mean rate: 0.039 events/800 s*



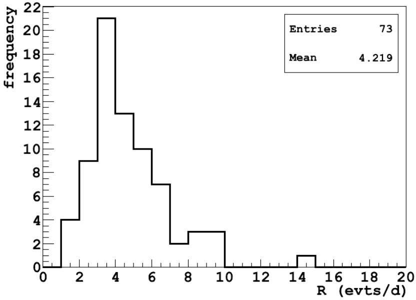
If random events happen with a mean number of occurences in a given time interval, then the number of occurrences within that time interval should follow a Poisson distribution:

n: number of events in 800 s intervals	**P(n|ν):** Poisson prob. to observe n events given the rate ν	**Expected number of occurences**	**Observed number of occurences**
0	0.96175	9123.2	9122
1	0.03751	355.8	357
2	0.00073	6.9	6
3	0.00001	0.1	1

Observed numbers consistent with expectations from a Poisson process.

Analysis of α-background

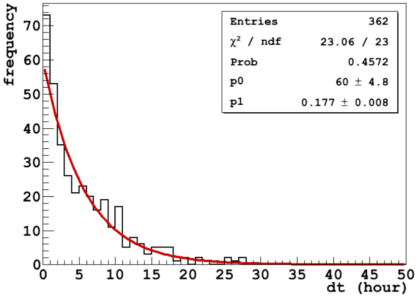
Daily count rate distribution of high-energy events from ch2. Mean rate: 4.219 events/day (corrected for data-taking interruptions by excluding the days affected by the interruptions).



n (events)	$P(n\|\nu)$	Expected	Observed
0	0.014713	1.1	0
1	0.062076	4.5	4
2	0.130949	9.6	9
3	0.184157	13.4	21
4	0.194240	14.2	13
5	0.163900	12.0	10
6	0.115249	8.4	7
$3 \leq n \leq 6$	0.657537	48.0	51
7	0.069462	5.1	2
8	0.036633	2.7	3
9	0.017173	1.3	3
≥ 9	0.028622	2.1	4
14	0.000096	$7 \cdot 10^{-3}$	1

If random events happen continuously with a constant mean rate, then the time between successive events should follow an exponential distribution:

Distribution of time difference between successive high-energy events from ch2.



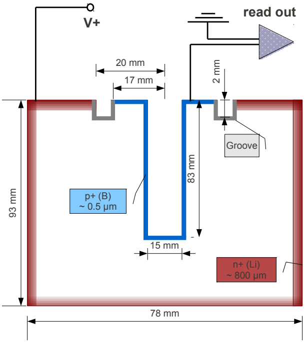
Events happen independently at a constant rate as expected from ^{210}Po α-decays at a constant rate, due to an initial ^{210}Pb surface contamination

Analysis of α-background

Simulation of ^{210}Po α-decays at detector surfaces

Simulation of ^{210}Po background is performed using *MaGe*, a Monte-Carlo package based upon Geant4 and ROOT libraries (developed by Majorana and GERDA collaborations).

p-type HPGe detector, cylindrical closed-end coaxial geometry



^{210}Po α-decays generated at the p+ contact assuming three different contamination scenarios:

1) on the surface, vary the dead layer (DL) thickness

2) inside an implantation depth assuming a flat density profile, vary the depth and the DL thickness

3) inside the whole DL assuming an exponential density profile: $f(z) = C \cdot e^{-Rz}$, vary the exponent and the DL thickness

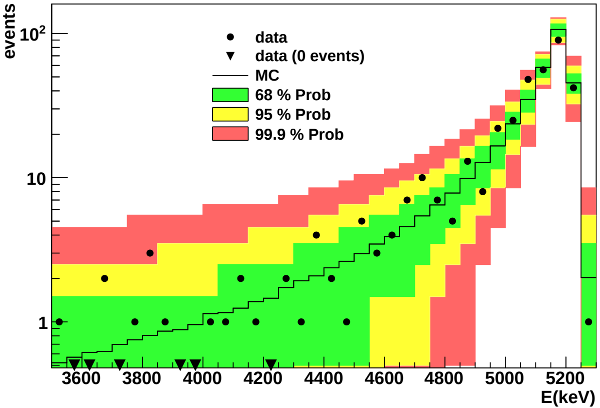
To compare with data, the resultant energy spectra were turned into probability density functions and used in maximum-likelihood fit:

$$P(D|N_{pDL}) = \prod_{i=1}^{Nbins} \frac{e^{-\nu_i} {\nu_i}^{n_i}}{n_i!}$$

n_i, ν_i: observed and expected number of events in the bins

Maximum-likelihood fit of the experimental spectrum from **ch2** in 3.5 MeV-5.3 MeV range.

Assumption: All events come from ^{210}Po α-decays inside a dead layer of 500 nm with an exponentially decreasing density profile

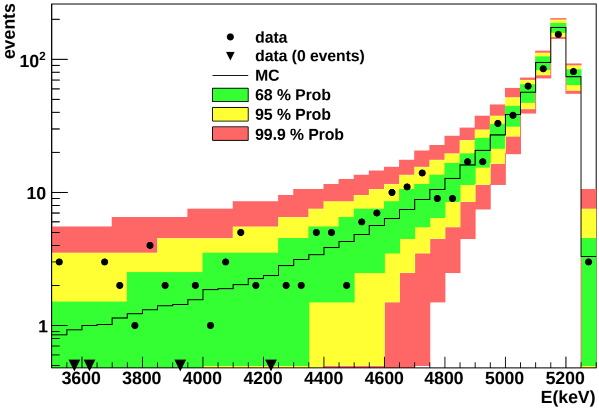


Analysis of α-background

Comparison of data with simulation

Maximum-likelihood fit of the experimental spectrum from **ch1+ch2+ch3+ch4+ch5+ch6** in 3.5 MeV-5.3 MeV range.

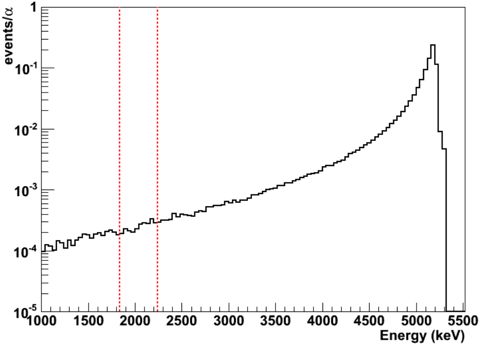
Assumption: All events come from ^{210}Po α-decays inside a dead layer of 500 nm with an exponentially decreasing density profile



Implication of background from surface ^{210}Po alphas

Model describes the high-energy spectrum observed in enriched detectors: ^{210}Po α-decays inside the dead layer (d=500nm) on surface with an exponentially decreasing density profile

Contribution of degraded ^{210}Po alphas in the ROI ($Q_{\beta\beta}\pm$ 200 keV):
$\rightarrow 8.8 \cdot 10^{-6}$ counts/keV per measured α-event in the peak (5.0 MeV-5.3 MeV)



For the enriched detectors (ch1-ch6):

- Bg contribution of degraded ^{210}Po α's

$\rightarrow$ **$BI_{\alpha} = 10^{-3}$ counts/(kg·y·keV)**

- Total background index

$\rightarrow$ **$BI_{tot} = 1.6 \cdot 10^{-2}$ counts/(kg·y·keV)**

in the ROI ($Q_{\beta\beta}\pm$ 200 keV) in Phase-I (exposure: 3.52 kg·y)

$\Rightarrow$ **about 6% contribution from α's**

Summary & Discussion

Summary:

- Alpha background observed in GERDA Phase-I analyzed.

  ▷ Majority of high-energy events assumed to originate from ^{210}Po α-decays in dead layer, due to an initial ^{210}Pb detector surface contamination

  ▷ Time behavior analysis: results consistent with a Poisson process

  ▷ MC simulation reproduce the energy spectrum (different models and parameters investigated)

  ▷ Background contribution from degraded surface alphas in the ROI for enriched detectors estimated: $\mathrm{BI}_\alpha = 10^{-3}$ counts/(kg·y·keV), about 6% of the total BI

Discussion:

- Implications for GERDA Phase-II:

  ▷ BI goal of Phase-II: 10^{-3} counts/(kg·y·keV)
  $\rightarrow$ α-background can become an important component

  However,

  ▷ p-type point contact BEGe detectors will be used in Phase-II
  $\rightarrow$ Relatively much smaller p+ contact & good surface event discrimination power with the help of PSD method (see the next talk from Tobias Bode).