α-Background characterization for the GERDA experiment

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Outline:

- Motivation.
- GERDA Phase-I data.
- Analysis of α-background.
- Implications.
- 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: $T^{0\nu}_{1/2}(^{76}\text{Ge}) > 1.9\times10^{25}$ y (90% C.L.) from HdM Collaboration [Eur. Phys. J. A 12, 147154 (2001)]

claim: $T^{0\nu}_{1/2}(^{76}\text{Ge}) = 1.2\times10^{25}$ y [Phys. Lett. B 586 (2004) 198-212]

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

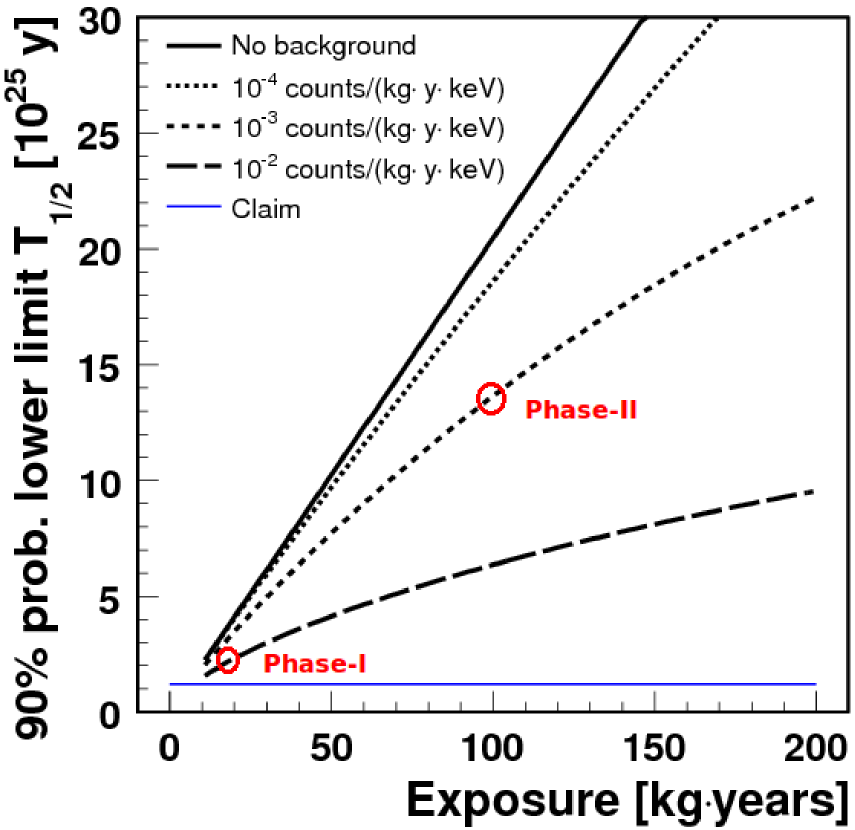
⇒ Increase the exposure (kg·y)

⇒ Lower the background index (BI: counts/(kg·y·keV) in ROI)

GERDA Phase-I: Test the claim

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

Lower BI ⇒ Background characterization & reduction

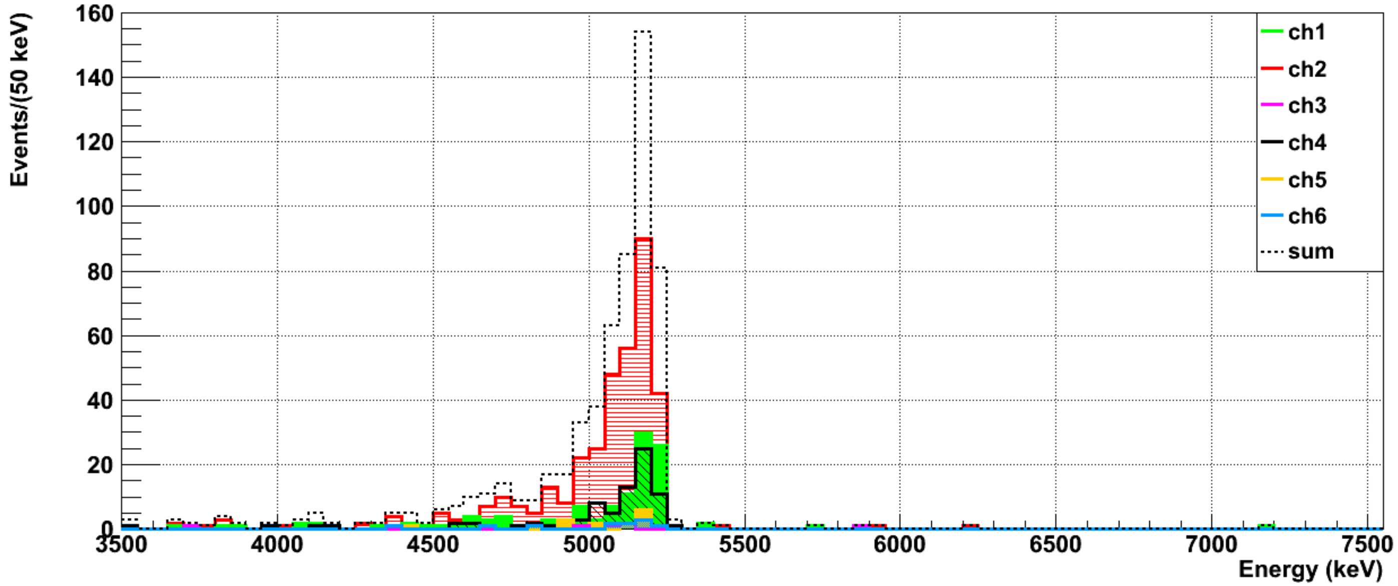


[Caldwell,Kröninger;Phys. Rev. D74, 092003 (2006)]

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

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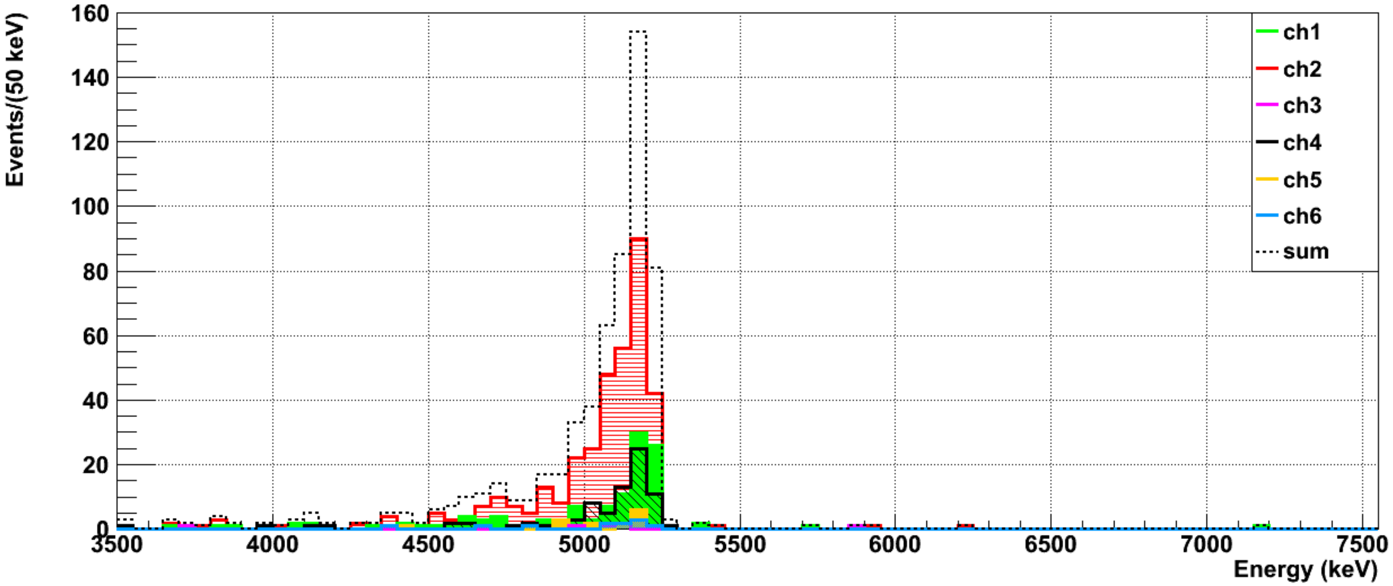


Range of an α in Ge: 10's of μm

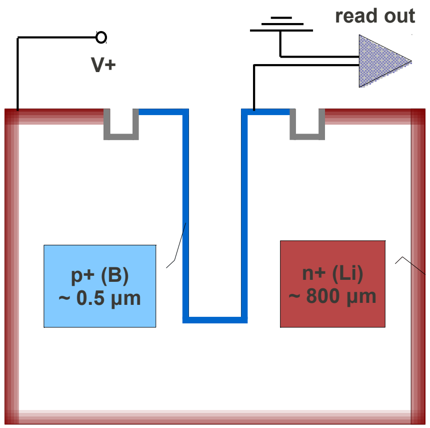
- **α-decays at detector surfaces**

$\Rightarrow$ can not traverse the thick dead layer (n+ layer: $\sim$800 μm)
$\Rightarrow$ energy loss and straggling in the thin dead layer (p+ layer: $\sim$0.5 μm) result in a peak structure

- **α-decays originating in materials external to the detector**

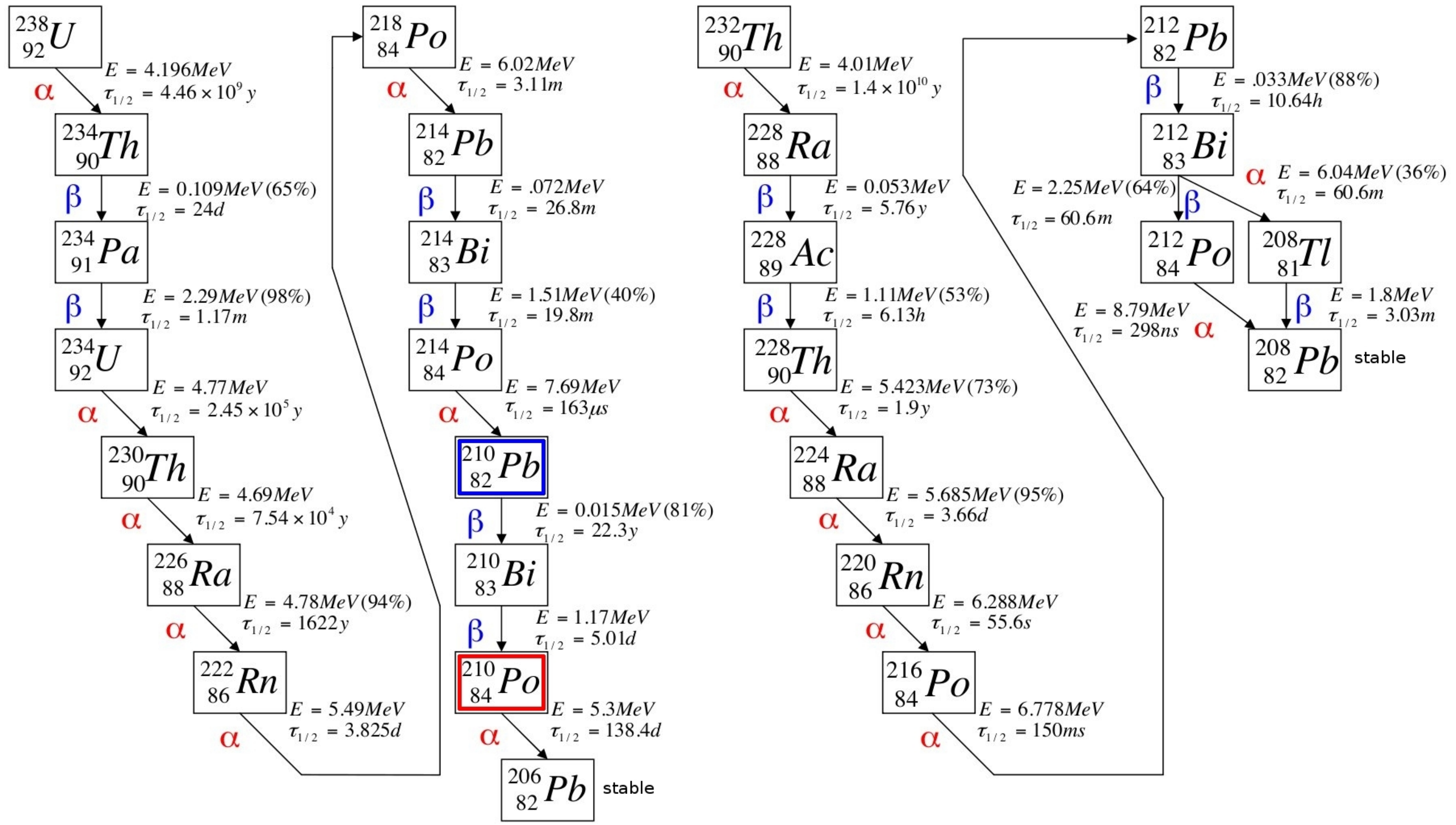
$\Rightarrow$ result in a broad spectrum without a peak structure

cylindrical, closed-ended coaxial geometry



Model: ^{210}Pb surface contamination

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

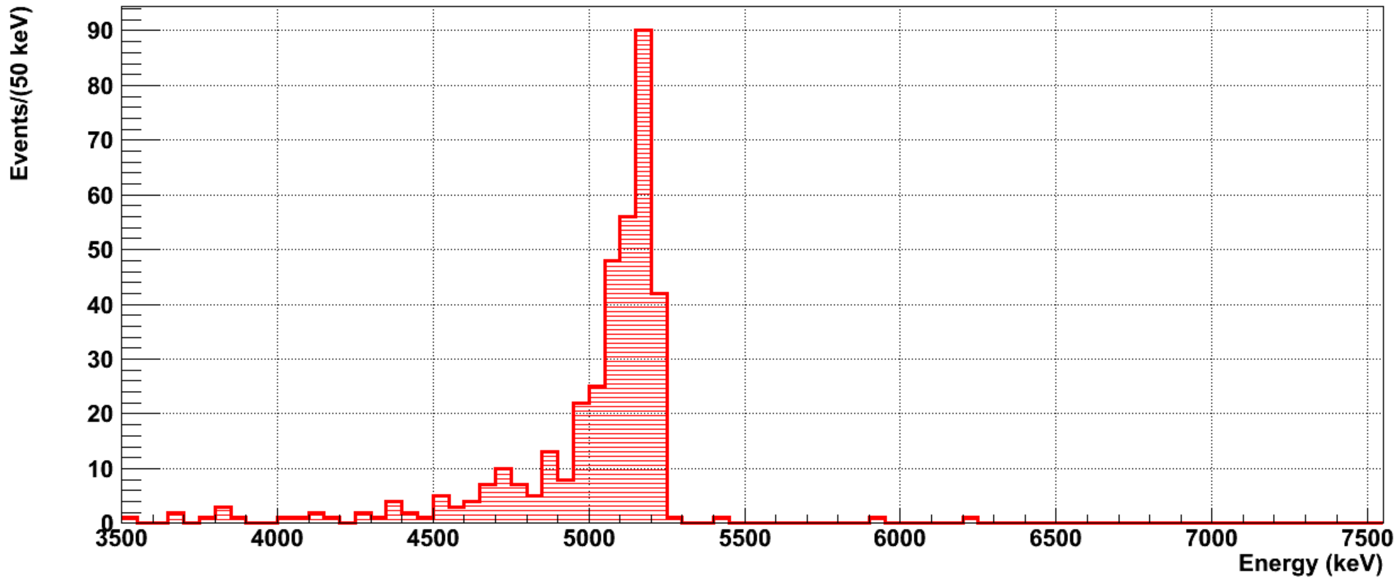


^{210}Pb surface contamination $\Rightarrow$ expect 5.3 MeV alphas from ^{210}Po at a constant rate (degraded spectrum at the dead layer)

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

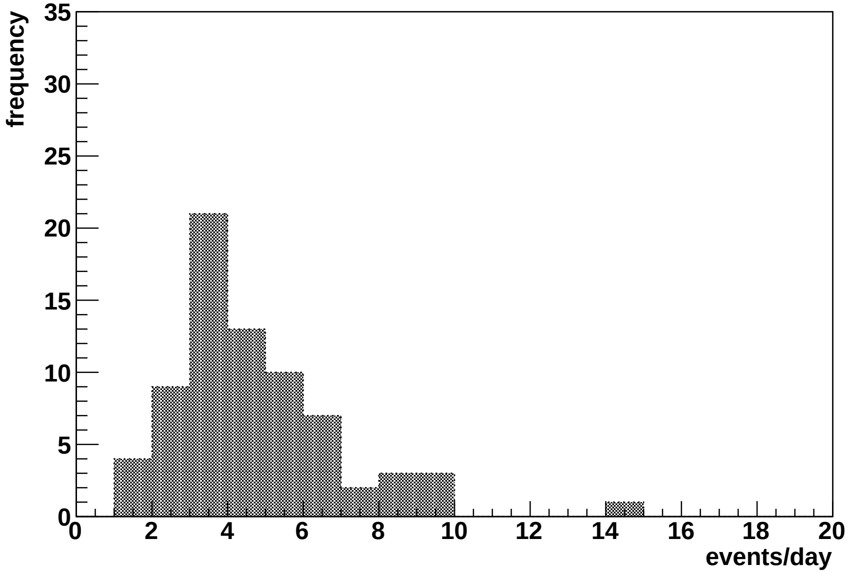


Assumption: Majority of high-energy events come from ^{210}Po α-decays (E = 5.3 MeV) at the surface, due to an initial ^{210}Pb surface contamination.

- Expect: Poisson process with a constant mean rate
- Reproduce the energy spectrum with a dedicated MC simulation

Analysis of α-background

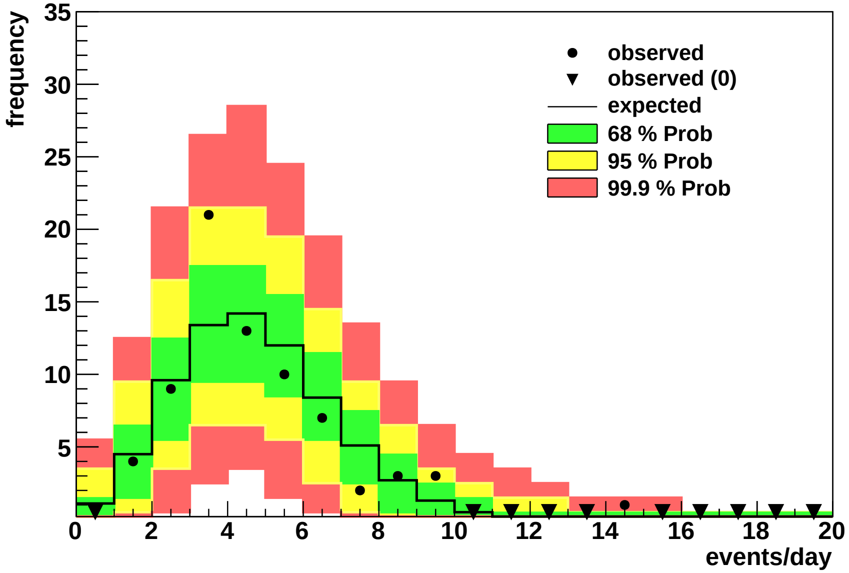
Daily count rate distribution of high-energy events from ch2 with a mean rate of ν=4.2 events/day *(corrected for data-taking interruptions by excluding the days affected by the interruptions).*



n (events/day)	P(n|ν)	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
7	0.069462	5.1	2
8	0.036633	2.7	3
9	0.017173	1.3	3
10	0.007245	0.5	0
11	0.002779	0.2	0
12	0.000977	$7\cdot10^{-2}$	0
13	0.000317	$2\cdot10^{-2}$	0
14	0.000096	$7\cdot10^{-3}$	1
$10\leq n\leq 14$	0.011414	0.8	1

Observed numbers consistent with expectations from a Poisson process.

Daily count rate distribution of high-energy events from ch2 with a mean rate of ν=4.2 events/day *(corrected for data-taking interruptions by excluding the days affected by the interruptions).*



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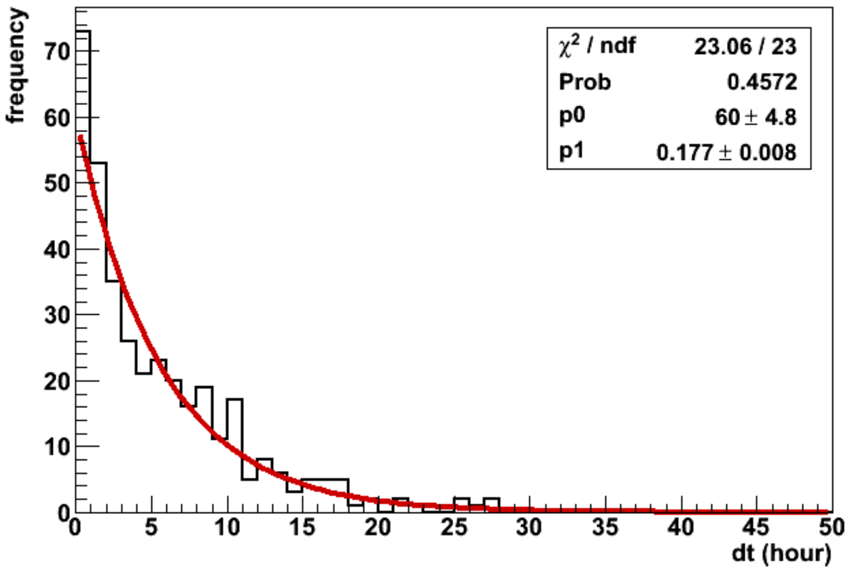
Observed numbers consistent with expectations from a Poisson process.

Time between successive events in a Poisson process follows an exponential distribution.

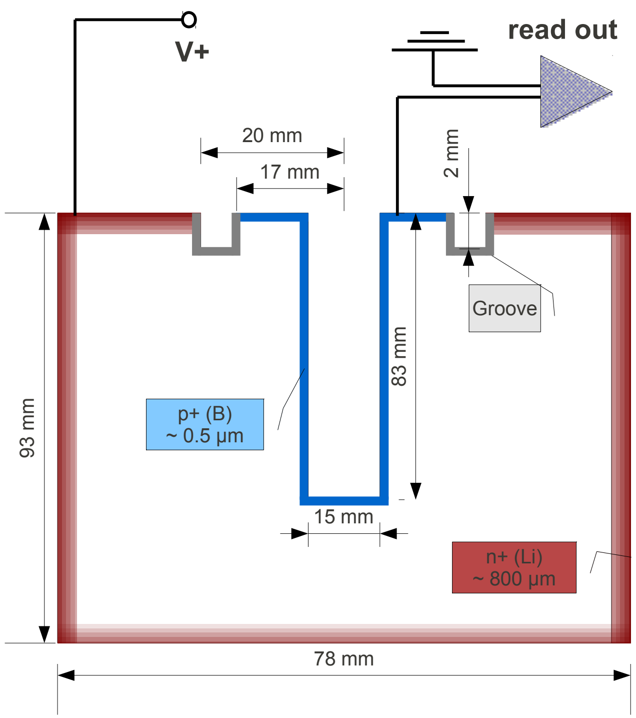
Distribution of time difference between successive high-energy events from ch2 *(corrected for data-taking interruptions)*



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

Simulation of ^{210}Po background is performed using *MaGe*, a physics simulation software framework based on Geant4 (developed by Majorana and GERDA collaborations)
[IEEE Trans. Nucl. Sci., vol. 58, no. 6 (2011)]

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



^{210}Po α-decays generated at the p+ layer 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

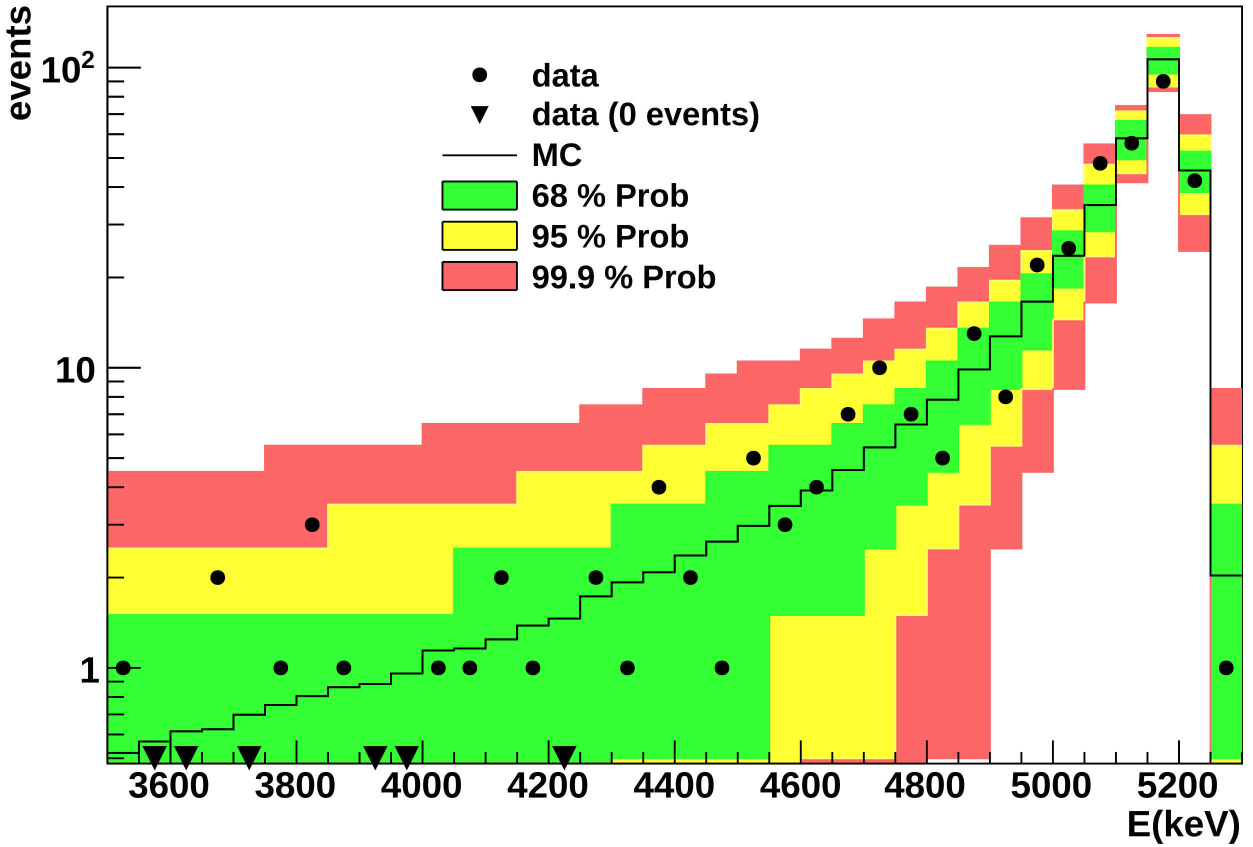
To compare simulations with data, the resultant energy spectra were turned into expectations and used in a maximum-likelihood fit:

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

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

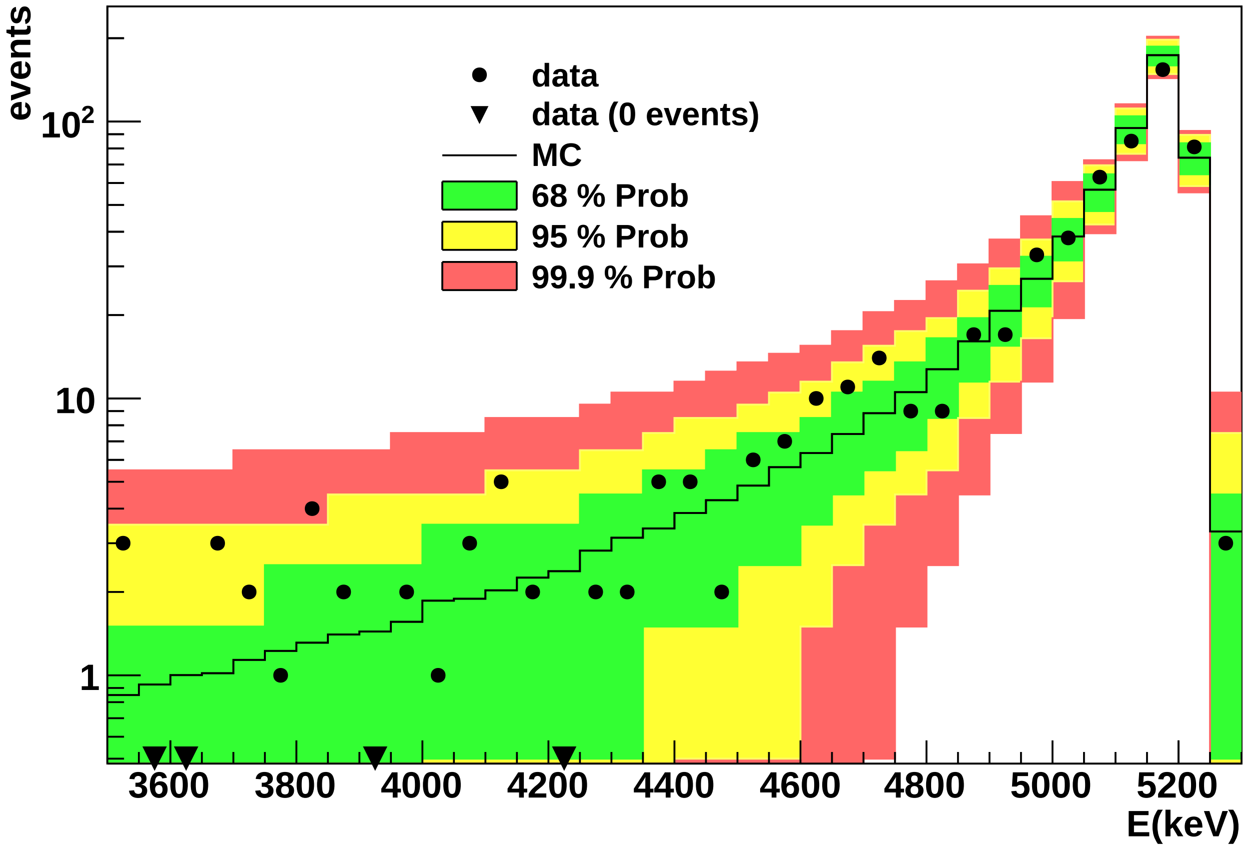
Maximum-likelihood fit of the experimental spectrum from **ch2** in 3.5 MeV-5.3 MeV range.

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



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

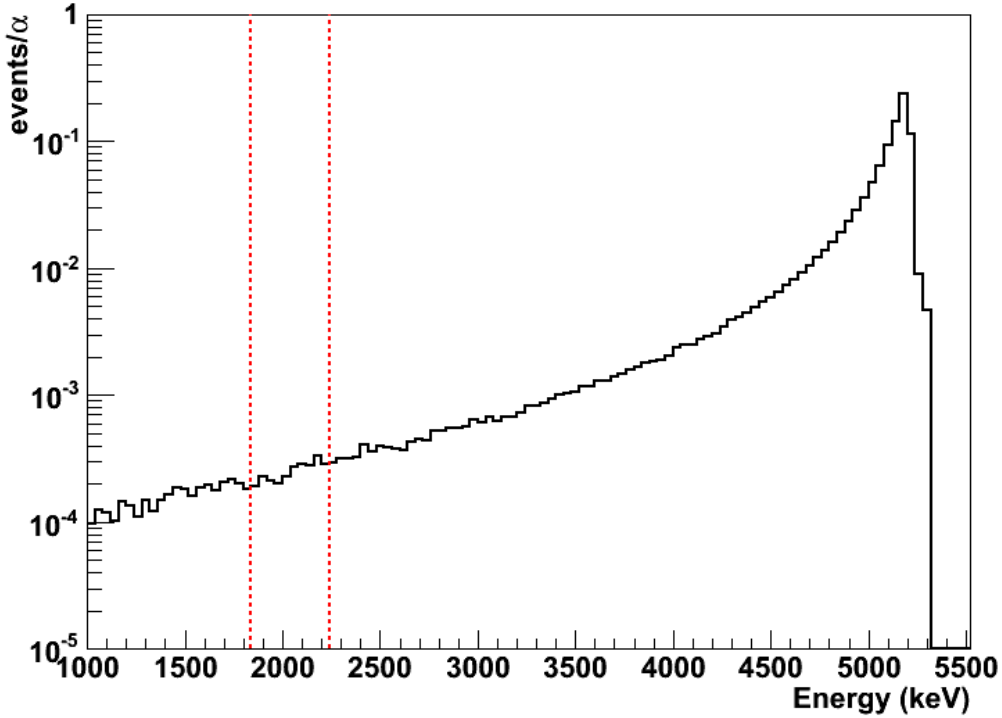
Assumption: All events come from ^{210}Po α-decays inside a dead layer of 500 nm with an exponentially decreasing density profile



Implication of background from surface ^{210}Po alphas

▷ Model describes the observed high-energy spectrum in 3.5 MeV-5.3 MeV range:
^{210}Po α-decays inside a dead layer of 500nm with an exponential density profile

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



For the enriched detectors in Phase-I (exposure: 3.52 kg·y)

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

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

- Total background index

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

in the ROI ($Q_{\beta\beta}\pm$ 200 keV)

⇒ **about 6% contribution to the BI from surface ^{210}Po α's**

Summary & Discussion

Summary:

- α-background observed in GERDA Phase-I analyzed.

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

  ▷ Results from time behavior analysis of events consistent with expectations from a Poisson process

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

  ▷ Background contribution from degraded surface ^{210}Po alphas in ROI for enriched detectors in Phase-I: **$BI_{\alpha} = 10^{-3}$ counts/(kg·y·keV), about 6% of the total bg index** $BI_{tot} = 1.6\cdot10^{-2}$ counts/(kg·y·keV)

Discussion:

- Implications for GERDA Phase-II:

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

  However,

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