Background characterization for the GERDA experiment

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MAX-PLANCK-GESELLSCHAFT

GERDA

Outline:

- Motivation
- GERDA Phase-I data and analysis:
  - modeling of the background components
  - decomposition of the background spectrum
- Conclusion

Motivation

GERDA experiment is searching for the 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]

GERDA Phase-I: $T_{1/2} > 2 \times 10^{25}$ y → test the claim

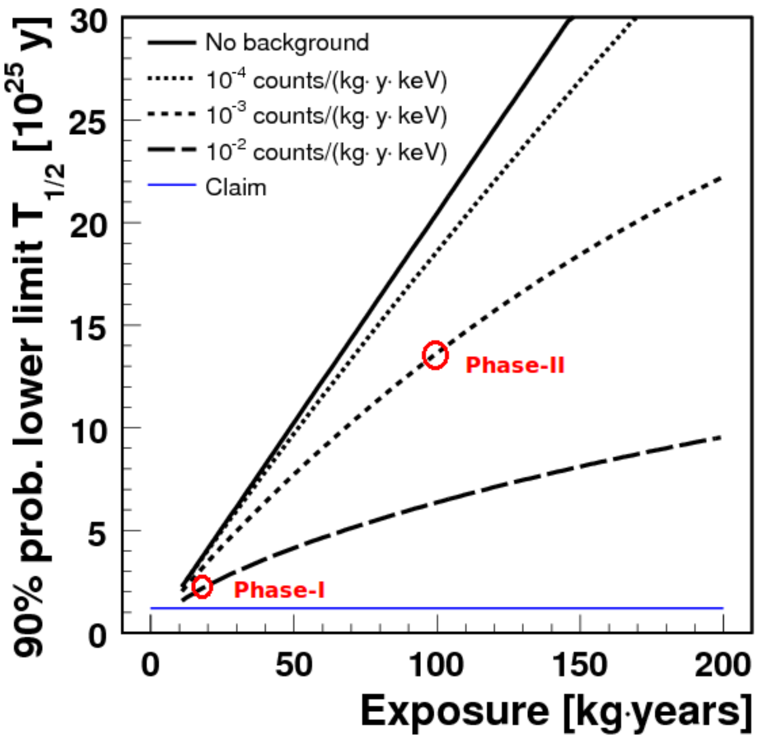
GERDA Phase-II: $T_{1/2} > 10^{26}$ y

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

→ larger exposure

→ lower background rate around $Q_{\beta\beta}$

▷ Background characterization & suppression

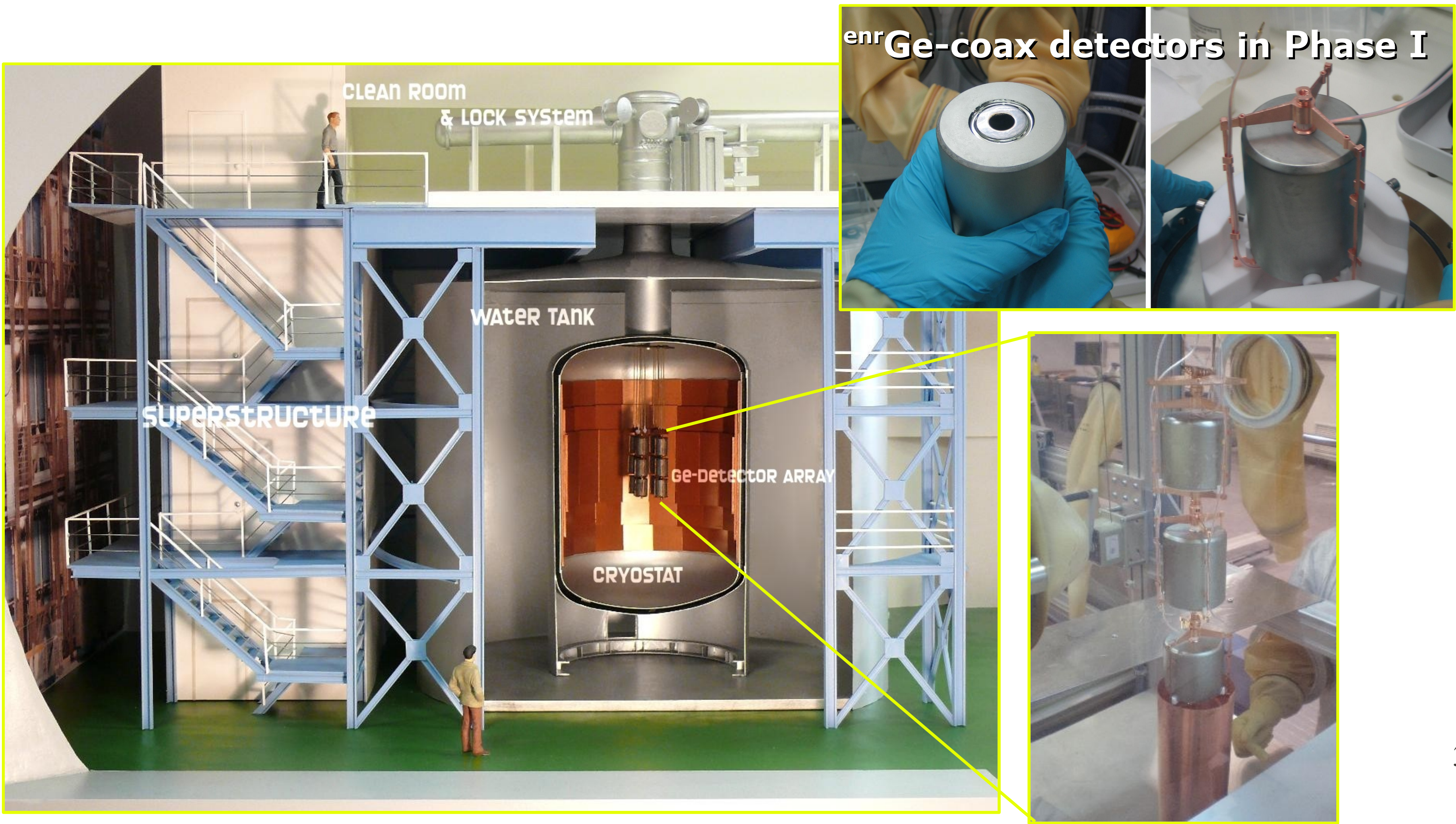


[Phys. Rev. D 74, 092003 (2006)]

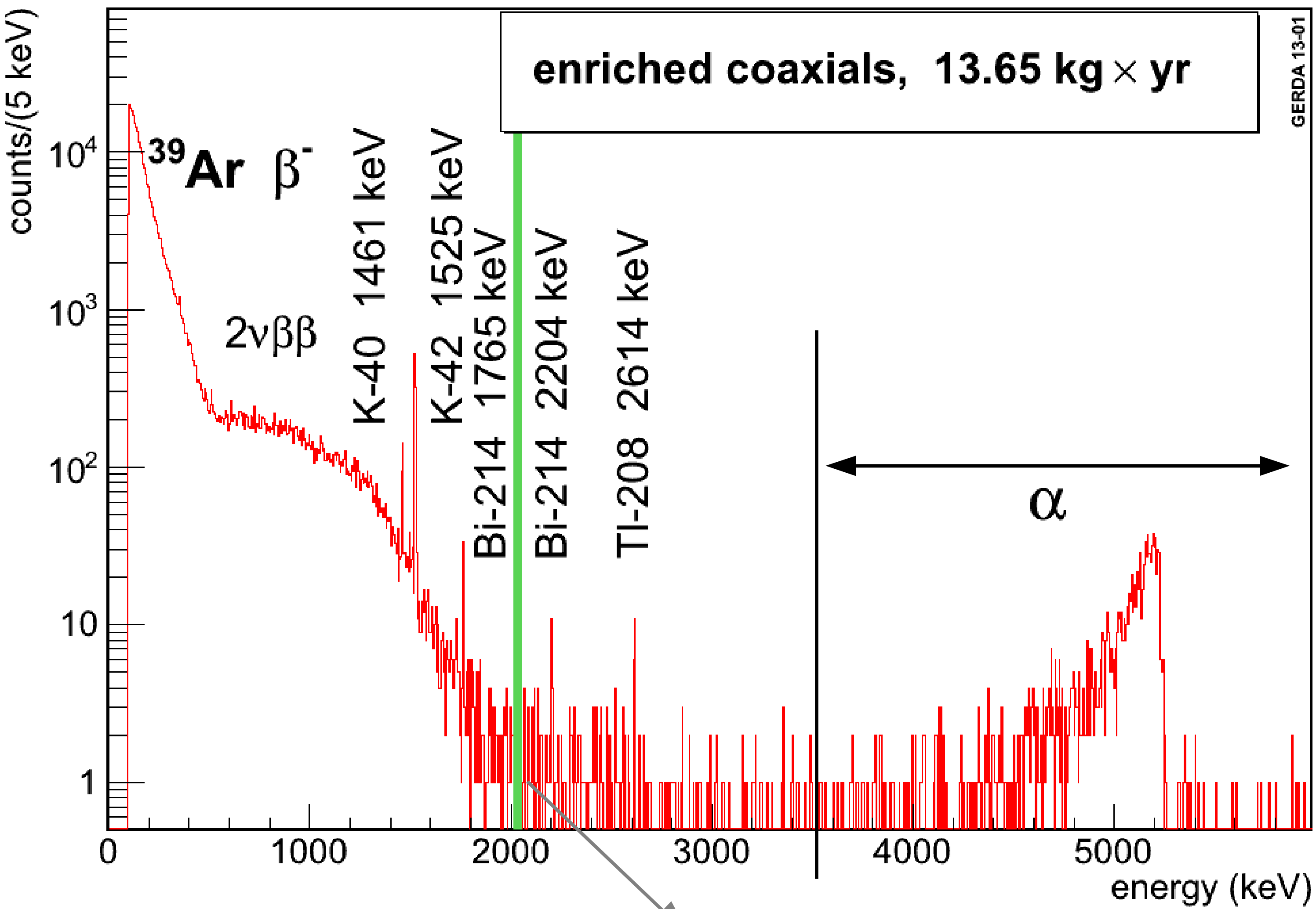
GERDA Phase I data

Considered data set:
9 November 2011 – 5 January 2013
→ total live DAQ time: 340.94 days
→ total mass of the coaxial type ^{enr}Ge detectors: 14.63 kg

total exposure: 13.65 kg x yr



GERDA Phase I data: background spectrum



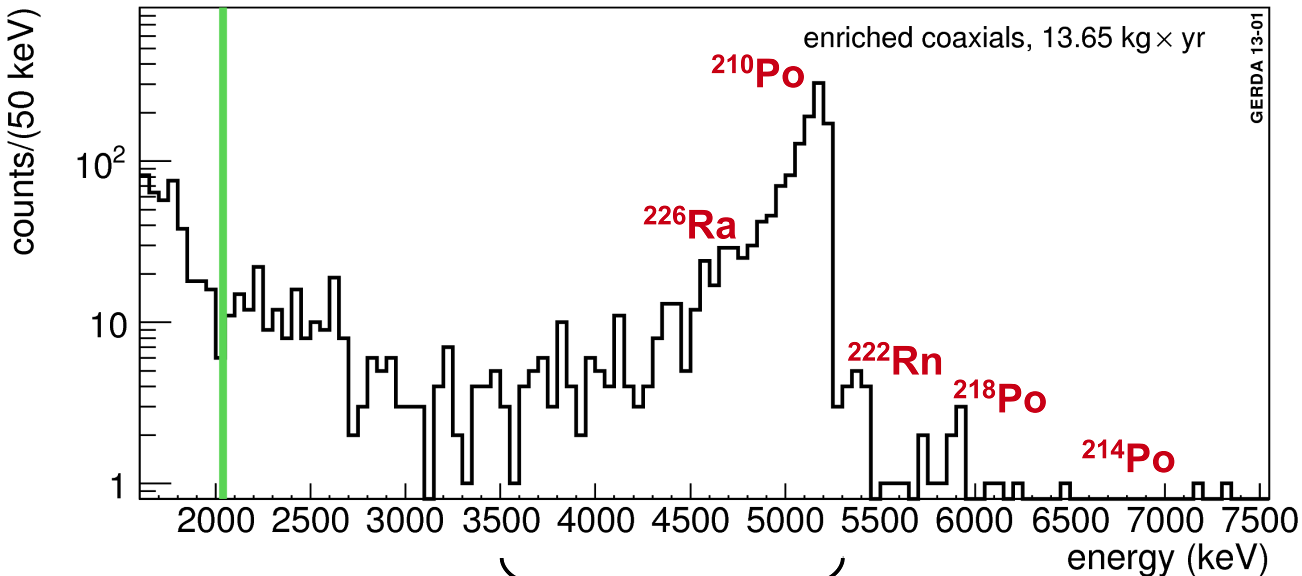
β-induced events expected up to 3525 keV

^{214}Bi (^{238}U) → Q_β = 3272 keV

^{42}K (^{42}Ar) → Q_β = 3525 keV

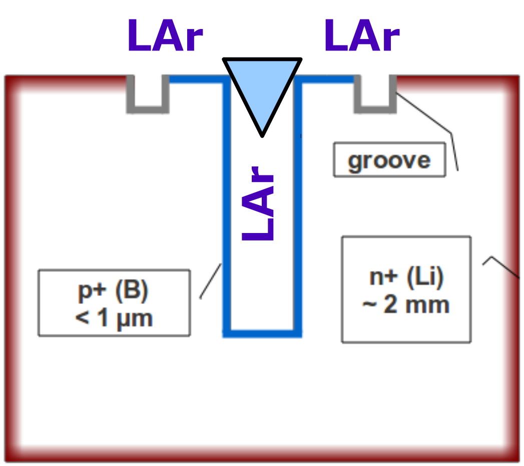
Blinded window around $Q_{\beta\beta}$ = 2039 keV
→ (2019 – 2059) keV

GERDA Phase I data: alpha-induced events



Exponential ($T_{1/2}$ = 138.4 d) + constant event rate

Constant event rate



- Range of alphas with E ~ 4 MeV – 9 MeV
  → 14 µm – 41 µm in Ge
  → 34 µm – 113 µm in LAr
- Possible origin of alpha-induced events:
  → ^{226}Ra and ^{210}Po contaminations on thin dead layer (thinDL) surfaces.

^{226}Ra (E_α = 4.8 MeV, $T_{1/2}$ = 1600 y)

^{222}Rn (E_α = 5.5 MeV, $T_{1/2}$ = 3.8 d)

^{218}Po (E_α = 6.0 MeV, $T_{1/2}$ = 183 s)

^{214}Pb ($T_{1/2}$ = 0.45 h)

^{214}Bi ($T_{1/2}$ = 0.33 h)

^{214}Po (E_α = 7.7 MeV, $T_{1/2}$ = 164 µs)

---

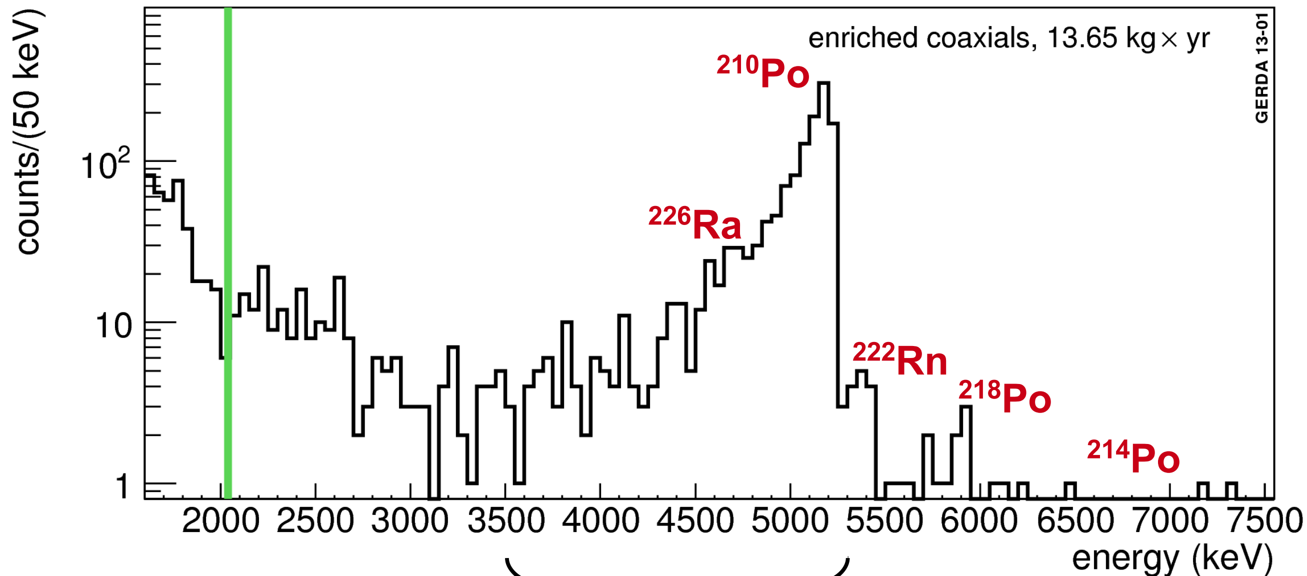
^{210}Pb ($T_{1/2}$ = 22.3 y)

^{210}Bi ($T_{1/2}$ = 5.01 d)

^{210}Po (E_α = 5.3 MeV, $T_{1/2}$ = 138.4 d)

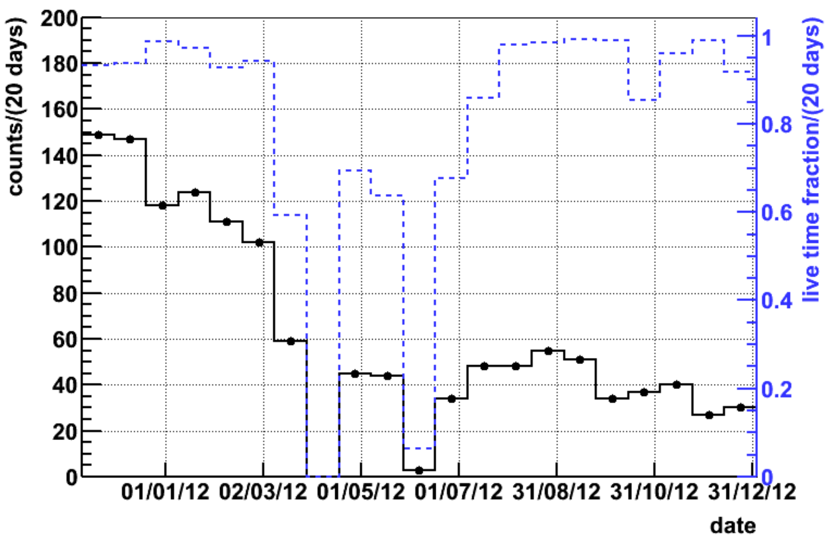
^{206}Pb (stable)

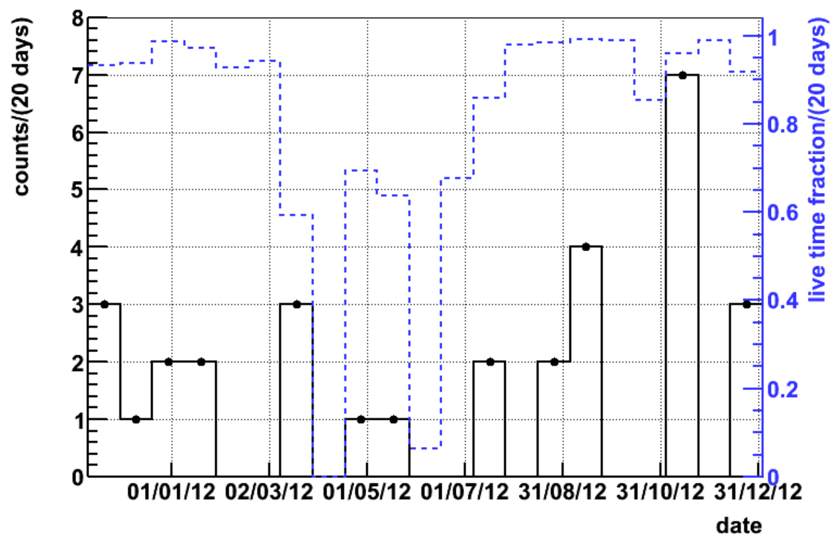
GERDA Phase I data: alpha-induced events



Exponential ($T_{1/2}$ = 138.4 d)
+ constant event rate

Constant event rate





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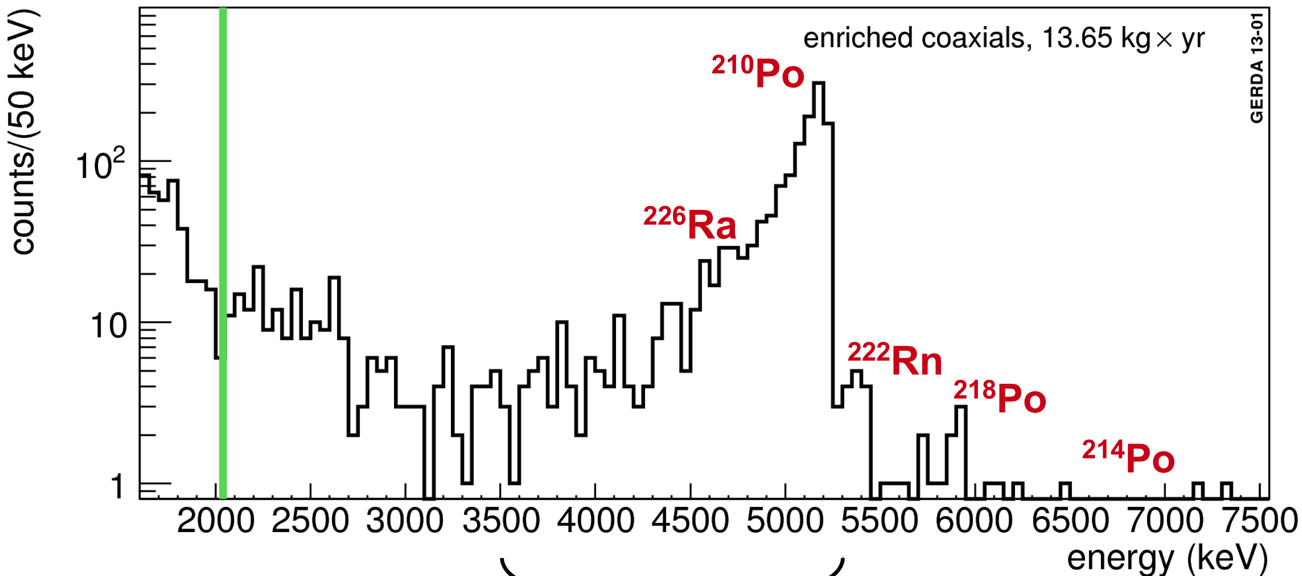
= 5.01 d)

: 5.3 MeV,

/2 = 138.4 d)

ble)

GERDA Phase I data: alpha-induced events



Exponential ($T_{1/2}$ = 138.4 d) + constant event rate

Constant event rate

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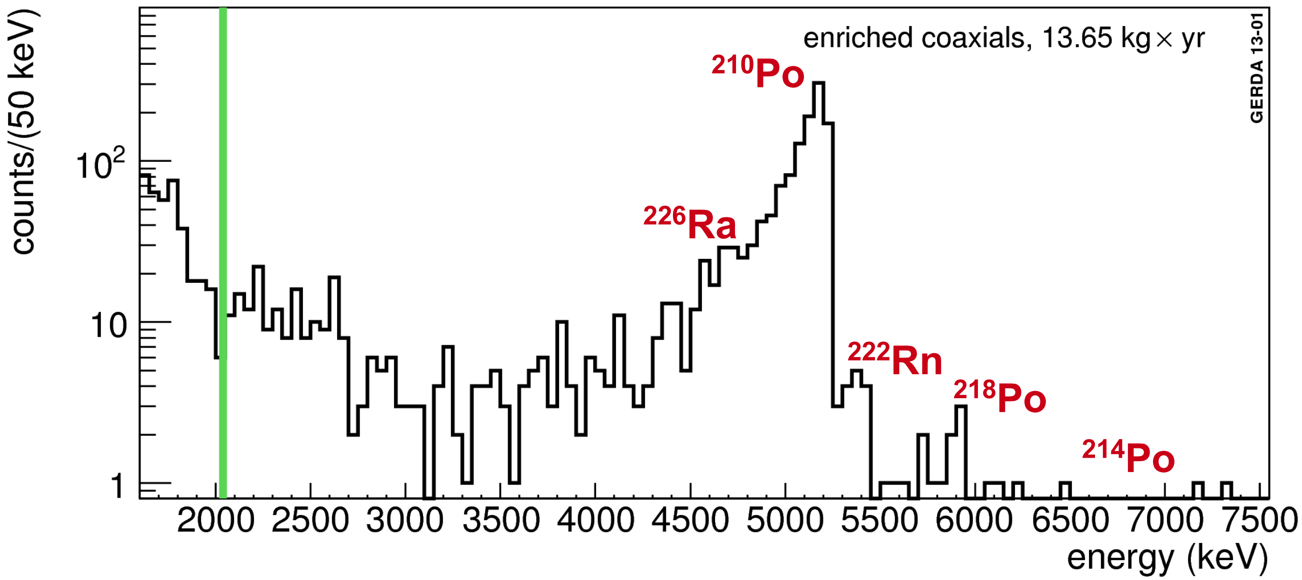
^{206}Pb (stable)

Results from fitting the event rate distributions (details in the backup) :

	C [cts/day]	N_0 [cts/day]	$T_{1/2}$ [days]	p-value
(3.5 MeV < E < 5.3 MeV)				
expo		9.26 ± 0.26	138.4 ± 0.2	0.11
expo + const	0.57 ± 0.16	7.91 ± 0.44	138.4 ± 0.2	0.87
(5.3 MeV < E < 7.5 MeV)				
const	0.09 ± 0.02			0.86

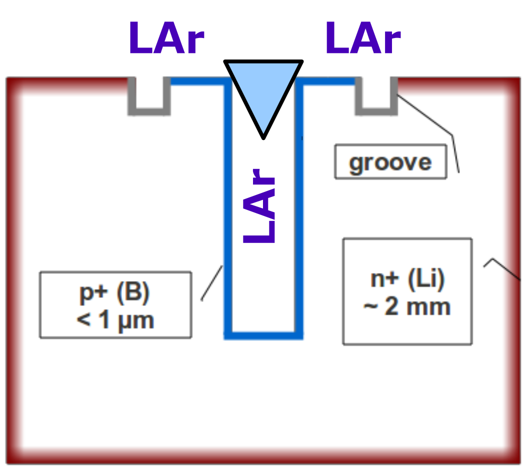
Given a strong prior probability on the half life parameter

GERDA Phase I data: alpha-induced events



MC simulations to model the energy spectrum:

1) ^{210}Po on thinDL surface
2) ^{226}Ra & daughters on thinDL surface
3) ^{222}Rn & daughters in LAr close to thinDL surface



- ^{222}Rn & daughters in LAr due to
  - → ^{226}Ra contamination on thinDL surface and on other materials close to detectors, e.g, holders of the detectors.

^{226}Ra (E_α = 4.8 MeV, $T_{1/2}$ = 1600 y)

^{222}Rn (E_α = 5.5 MeV, $T_{1/2}$ = 3.8 d)

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^{214}Pb ($T_{1/2}$ = 0.45 h)

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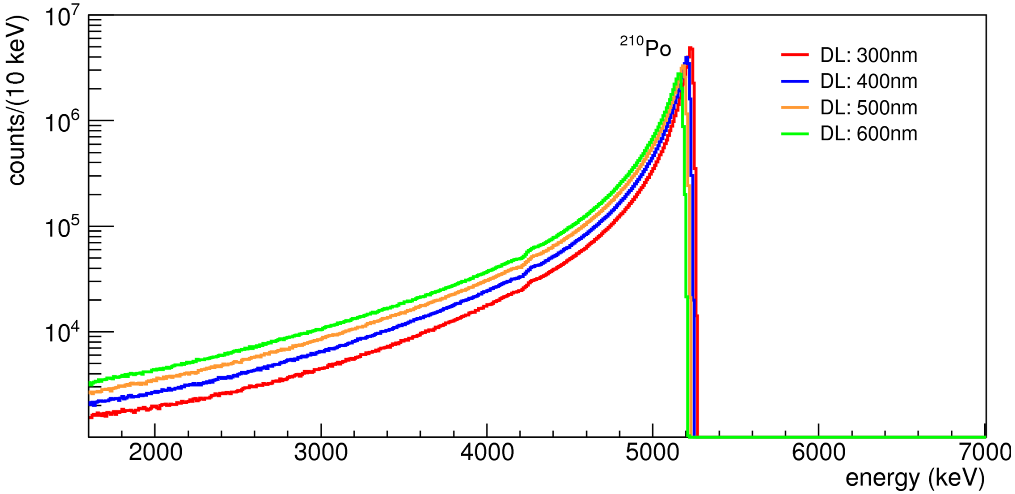
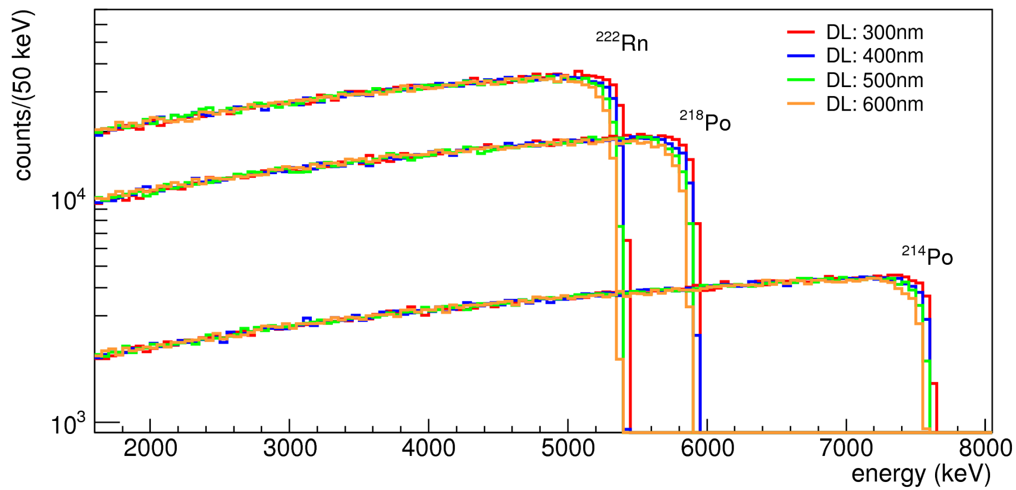
GERDA Phase I data: alpha-induced events

Simulated energy spectrum of different model components

^{210}Po on thinDL surface



^{222}Rn & daughters in LAr close to thinDL surface



Binned maximum posterior fit to the sum ^{enr}Ge-coax spectrum in (3500 – 7500) keV window

Maximized the posterior probability using Markov Chain Monte Carlo in Bayesian Analysis Toolkit BAT:

[A. Caldwell et. al., Comput. Phys. Commun. 180, 2197 (2009)]

Posterior probability: $$\boxed{P(\vec{\lambda}|\vec{n}) \propto P(\vec{n}|\vec{\lambda})P_0(\vec{\lambda})}$$

Likelihood:

$$\boxed{P(\vec{n}|\vec{\lambda}) = \prod_i P(n_i|\lambda_i) = \prod_i \frac{e^{-\lambda_i}\lambda_i^{n_i}}{n_i!}}$$

n_i number of observed, λ_i number of expected events in i-th bin

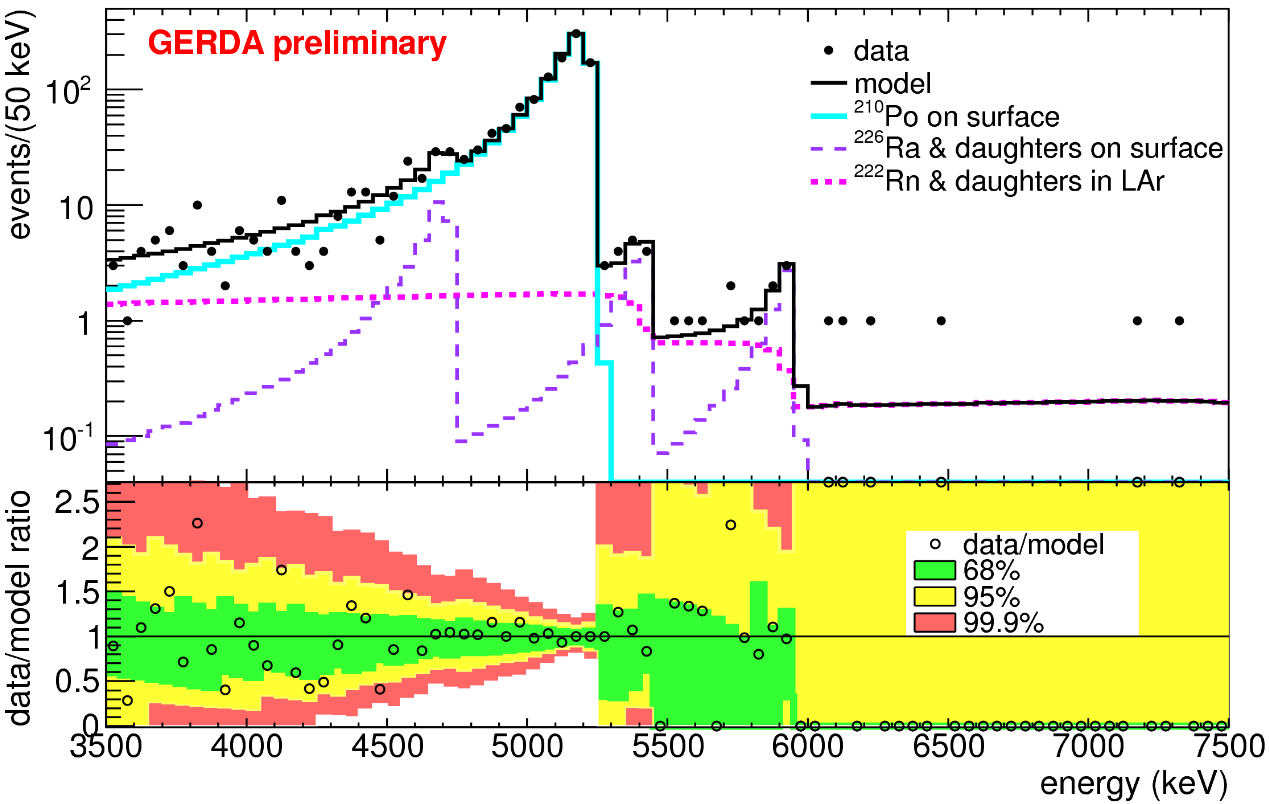
$$\lambda_i = \sum \lambda_{i,M}$$ → sum contribution of each model component M

$$\lambda_{i,M} = N_M \int_{\Delta E_i} f_M(E)dE$$

↓ scaling parameter for the component M

GERDA Phase I data: alpha-induced events

Experimental energy spectrum of sum ^{enr}Ge-coax detectors together with the best fit model:

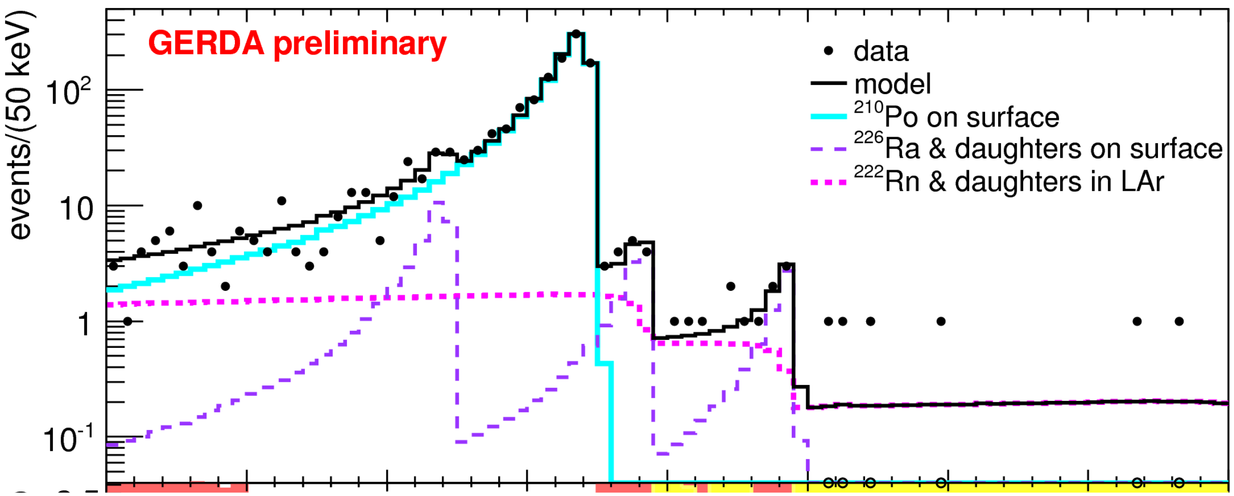


- fit window: (3500 – 7500) keV
- p-value of the fit: 0.7
- 80 bins of width 50 keV:
  79% in the green band
  98% in the yellow band

Colored probability intervals: [R. Aggarwal and A. Caldwell, Eur. Phys. J. Plus 127 24 (2012)]

GERDA Phase I data: alpha-induced events

Experimental energy spectrum of sum ^{enr}Ge-coax detectors together with the best fit model:



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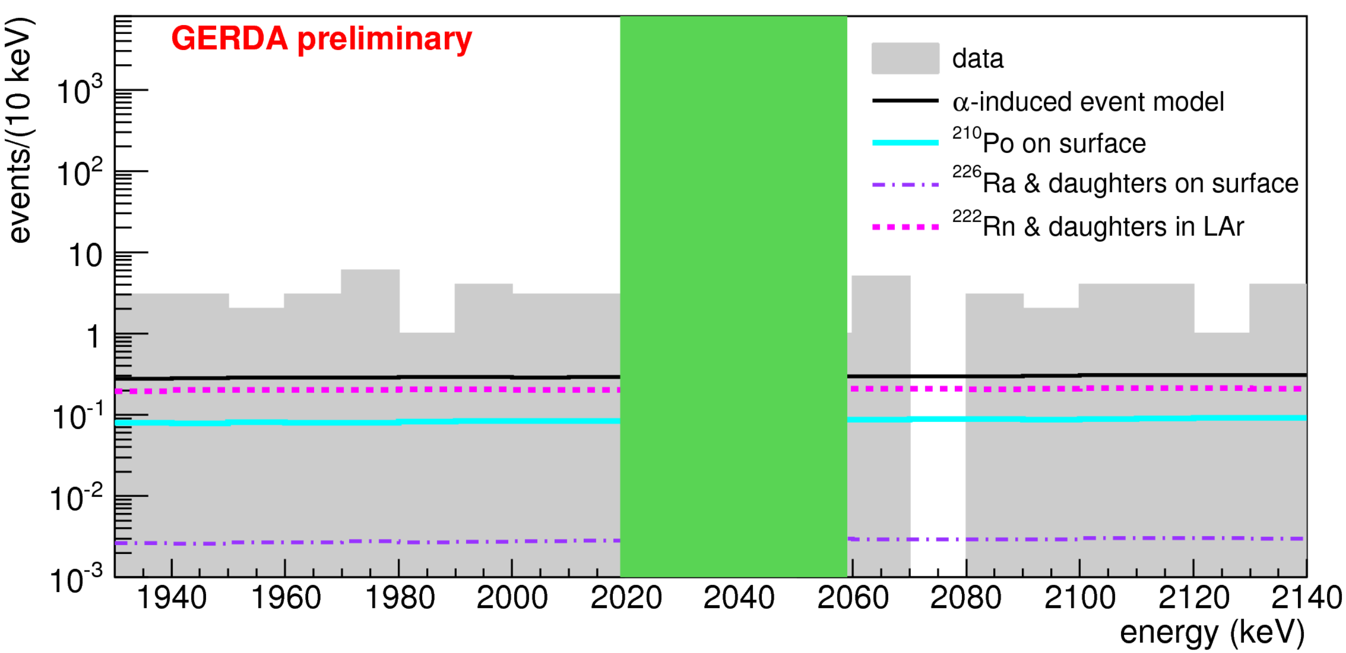
Extrapolation of the alpha-induced event model to ROI (160 keV):
(1939 – 2019) plus (2059 – 2139) keV



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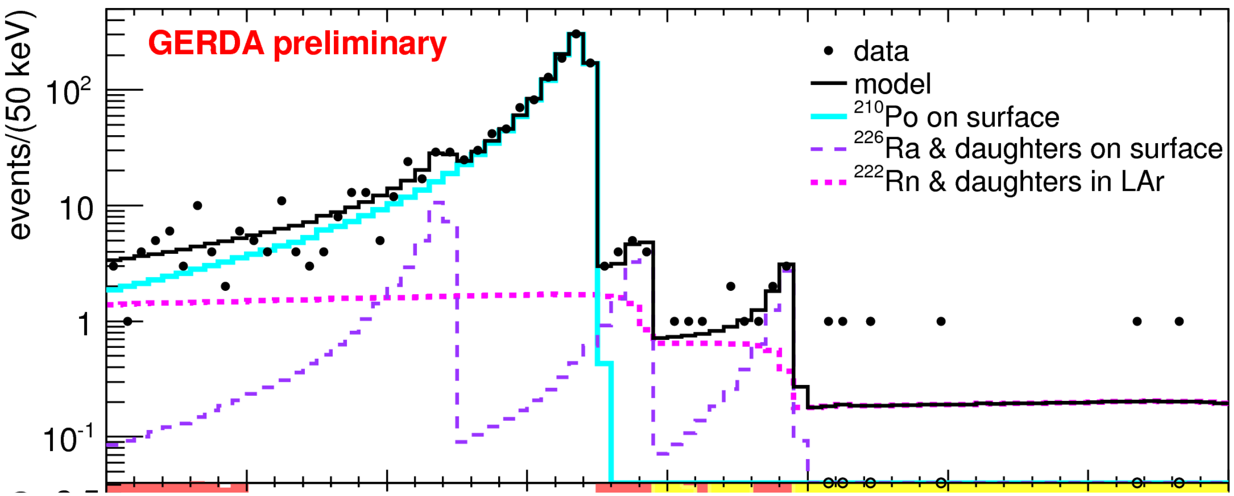

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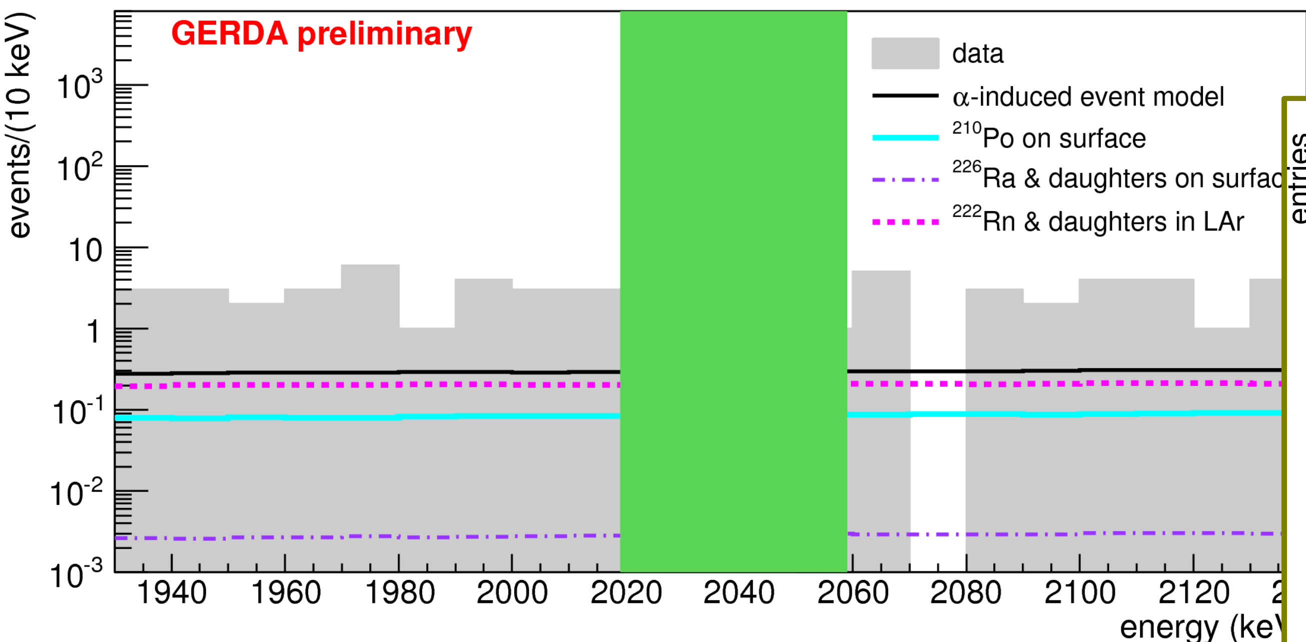
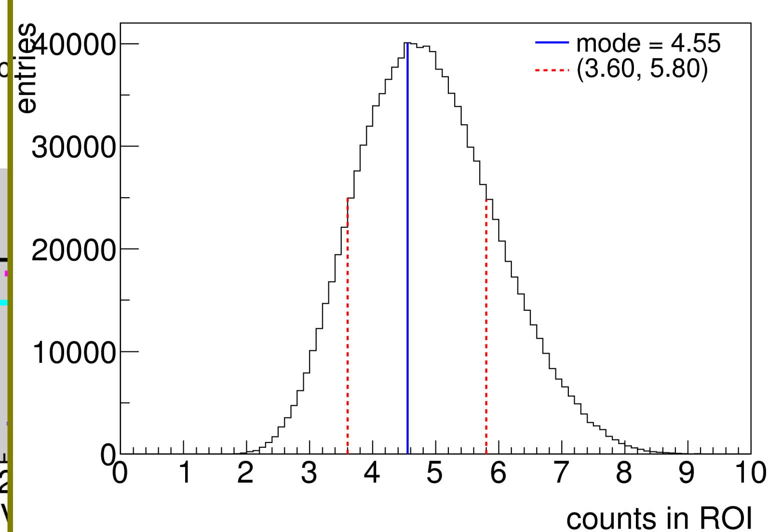
Extrapolation of the alpha-induced event model to ROI (160 keV):
(1939 – 2019) plus (2059 – 2139) keV

→ data: 49 events

→ alpha model: $4.55^{+1.25}_{-0.95}$ events

~ 9% contribution from alphas



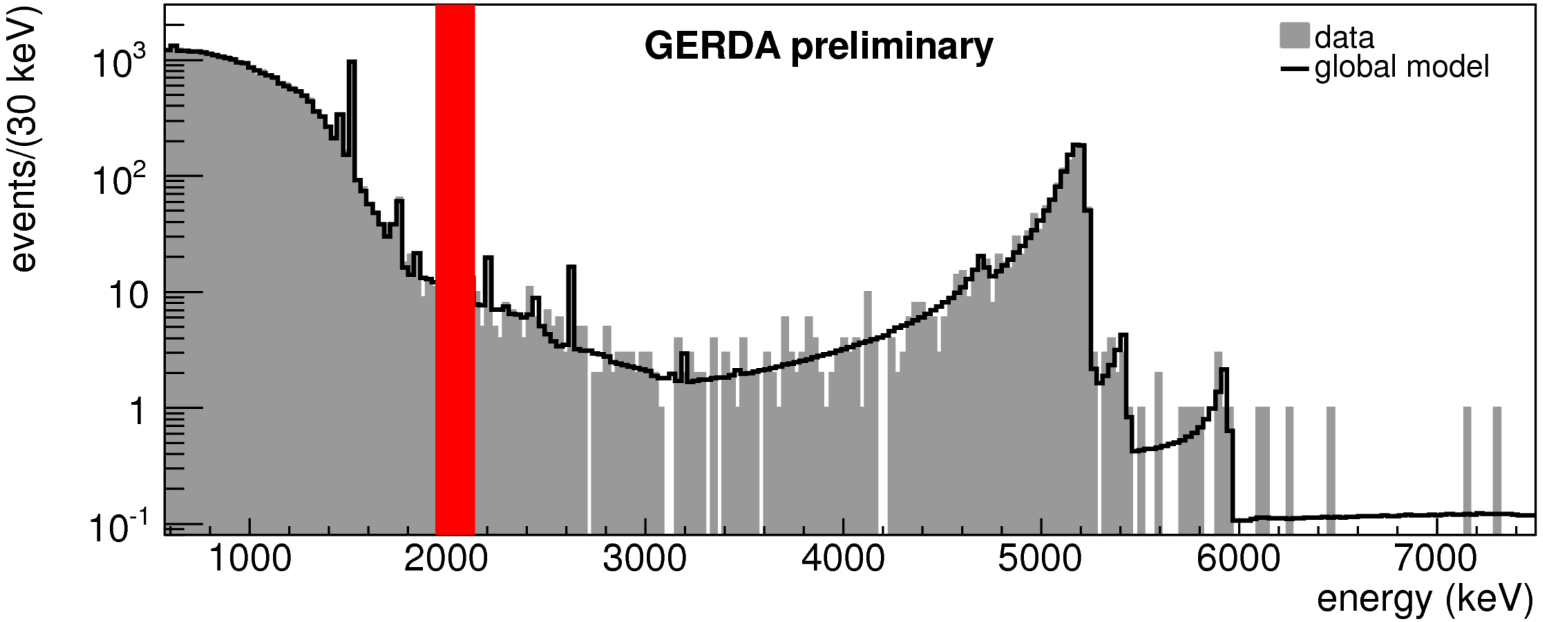


GERDA Phase I data: decomposition of the bg spectrum

Binned maximum posterior fit to the sum ^{enr}Ge-coax spectrum in (570 – 7500) keV window

- fit window enlarged to include $Q_{\beta\beta}$
- background components considered in the global fit:
  → K-42, K-40, Bi-214, Ac-228 & Th228 (beta- / gamma-induced events)
  and alpha-induced event model
- p-value of the fit: 0.3

Experimental energy spectrum of sum ^{enr}Ge-coax detectors together with the best fit model:



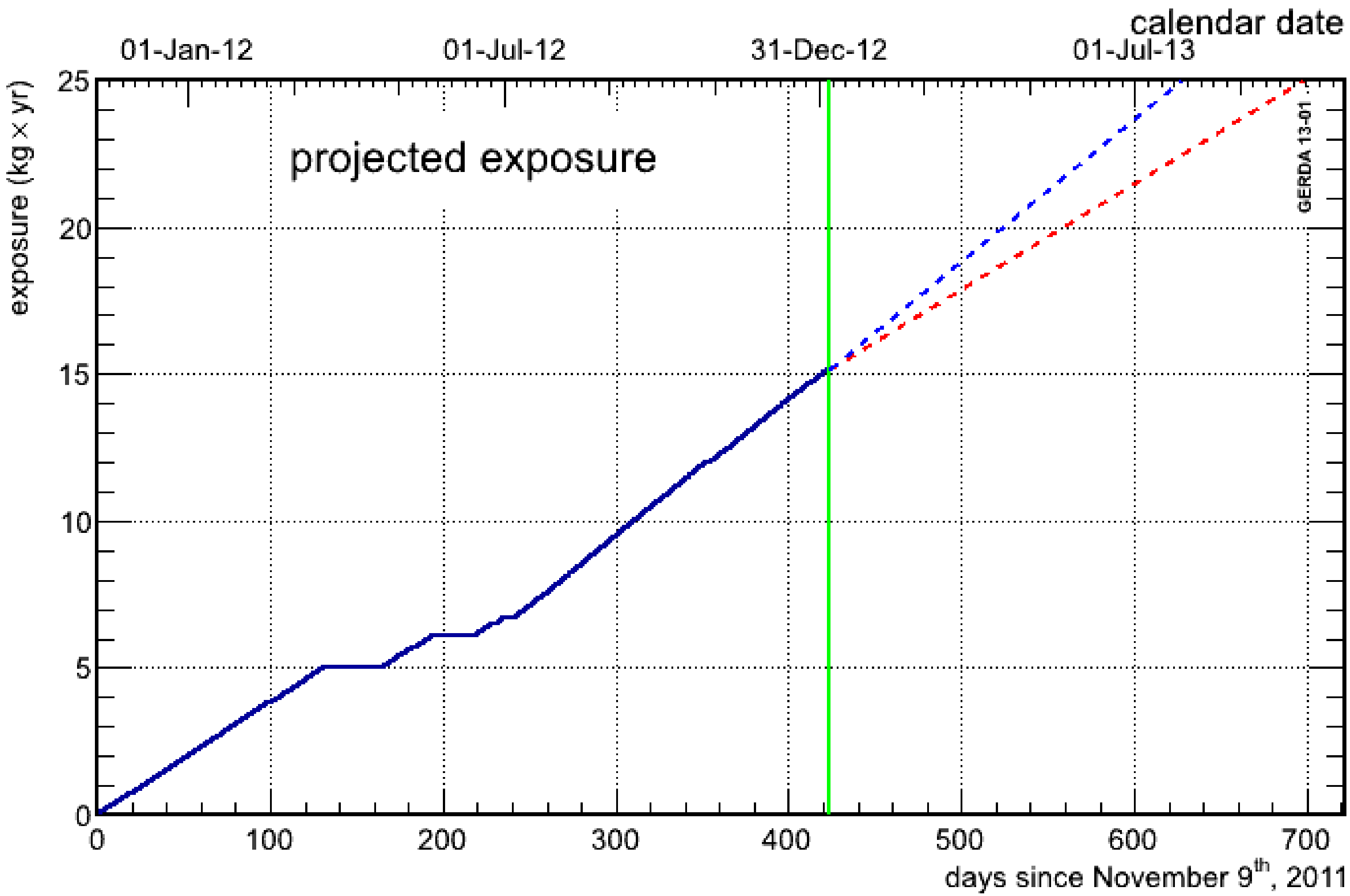
Main background contributions around $Q_{\beta\beta}$
→ K-42, Bi-214, Tl-208 and alphas

Conclusion

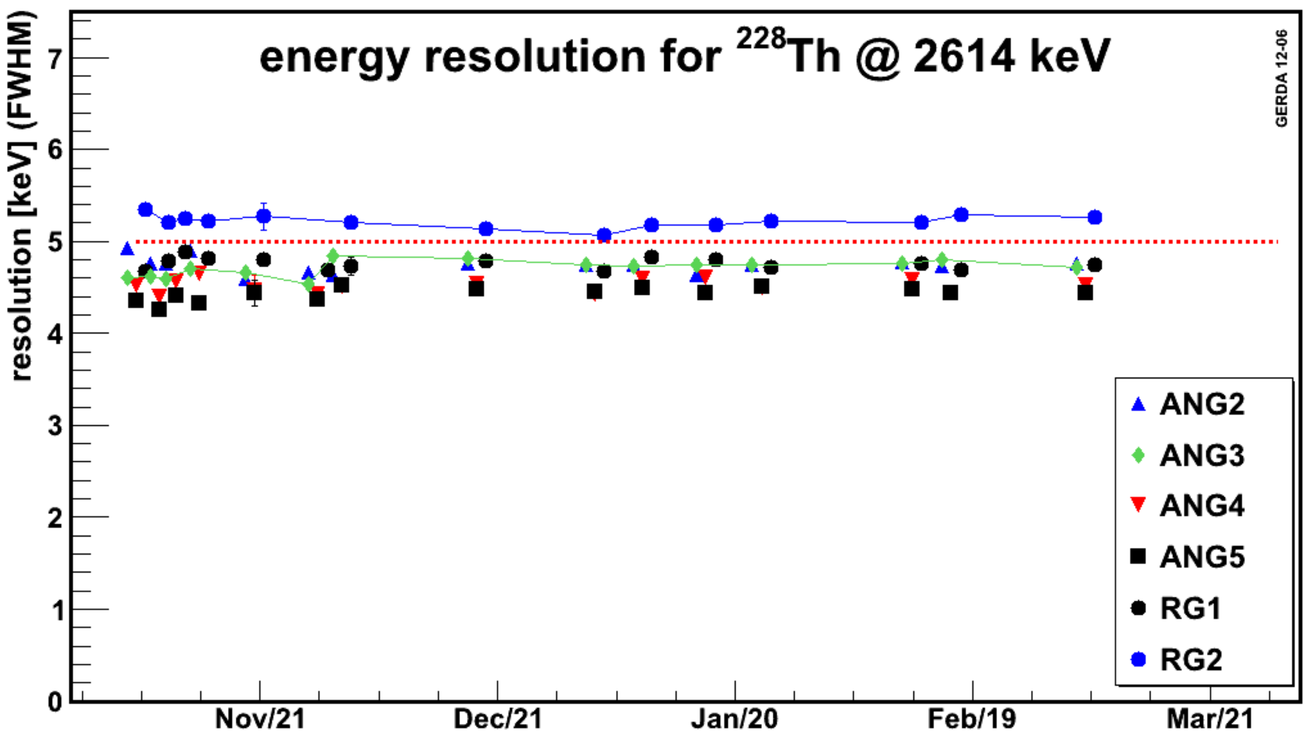
- GERDA Phase I data-taking is ongoing.
- Blind analysis: 40 keV window around $Q_{\beta\beta}$ = 2039 keV is blinded.
- Model the background energy spectrum before unblinding: Promising “preliminary” results !
- Background model is important:
  - understand the background in Phase I & mitigate it further in Phase II
  - estimate the expected number of background events & the shape of the background spectrum around $Q_{\beta\beta}$ for the upcoming $0\nu\beta\beta$ analysis.

Backup

GERDA Phase I data



GERDA Phase I data



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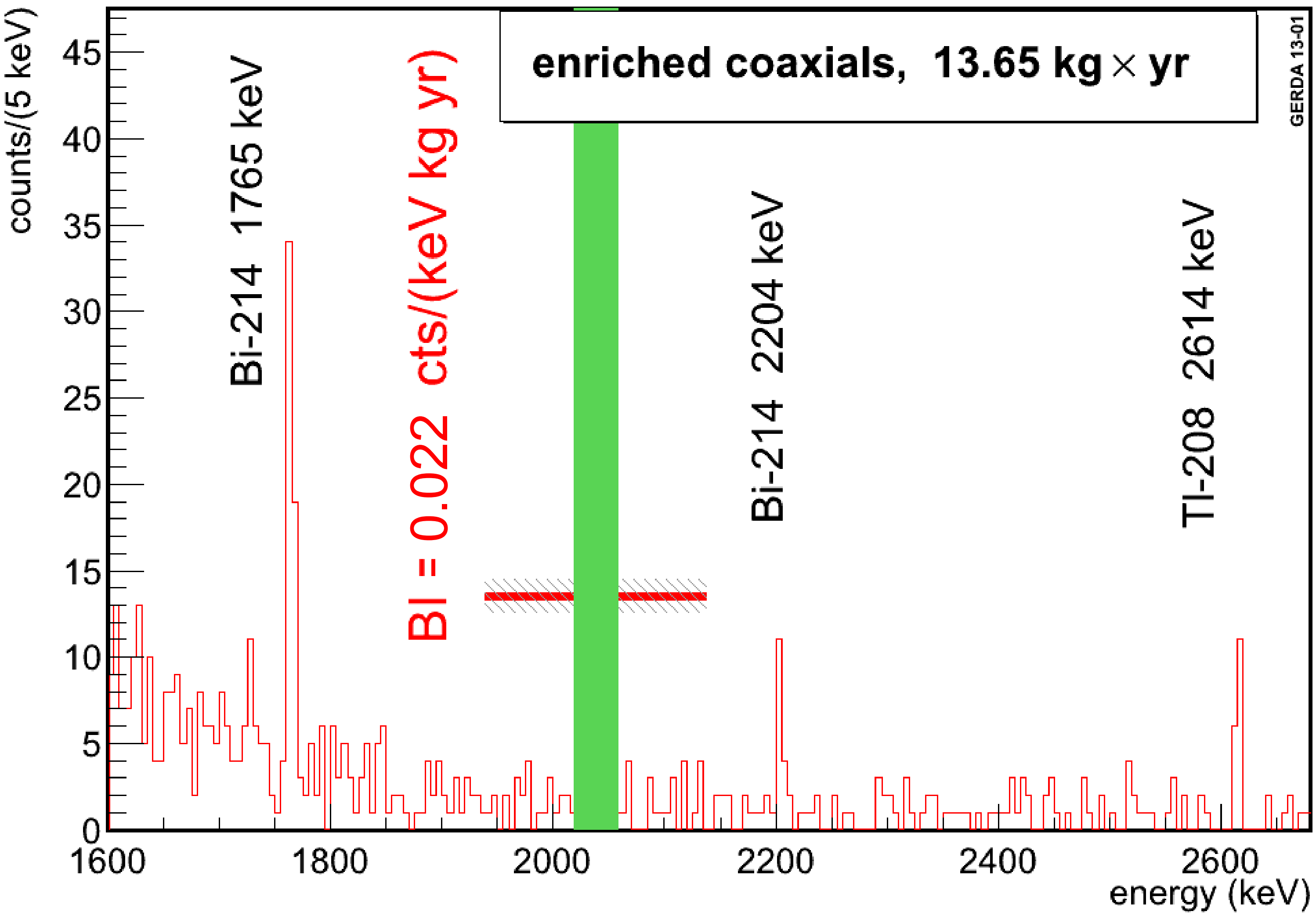
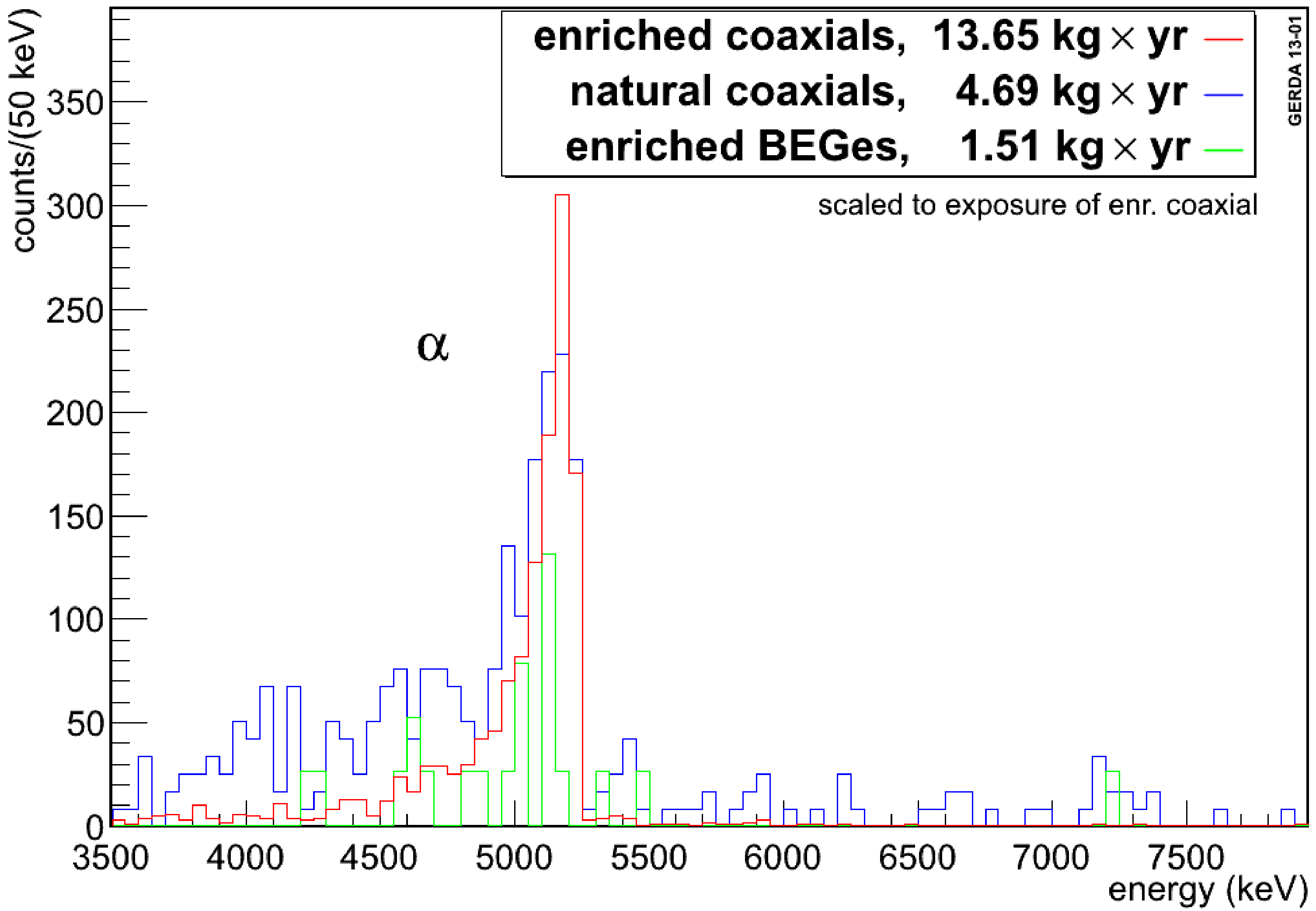


GERDA Phase I data



GERDA Phase I data: alpha-induced events

Analysis of event rate distributions:

- Fit the distribution with an exponential function

$$\boxed{N(t) = N_0 \cdot e^{-ln2\, t/T_{1/2}}}$$

- Maximized quantity posterior probability:

$$\boxed{P(\vec{\lambda}|\vec{n}) \propto P(\vec{n}|\vec{\lambda}) P_0(\vec{\lambda})}$$

- Set a prior on the half life parameter:

$P_0\,(T_{1/2})$ = Gaus(138.4 days, 0.2 days)

half-life of ^{210}Po

- Likelihood:

$$\boxed{P(\vec{n}|\vec{\lambda}) = \prod_i P(n_i|\lambda_i) = \prod_i \frac{e^{-\lambda_i}\lambda_i^{n_i}}{n_i!}}$$

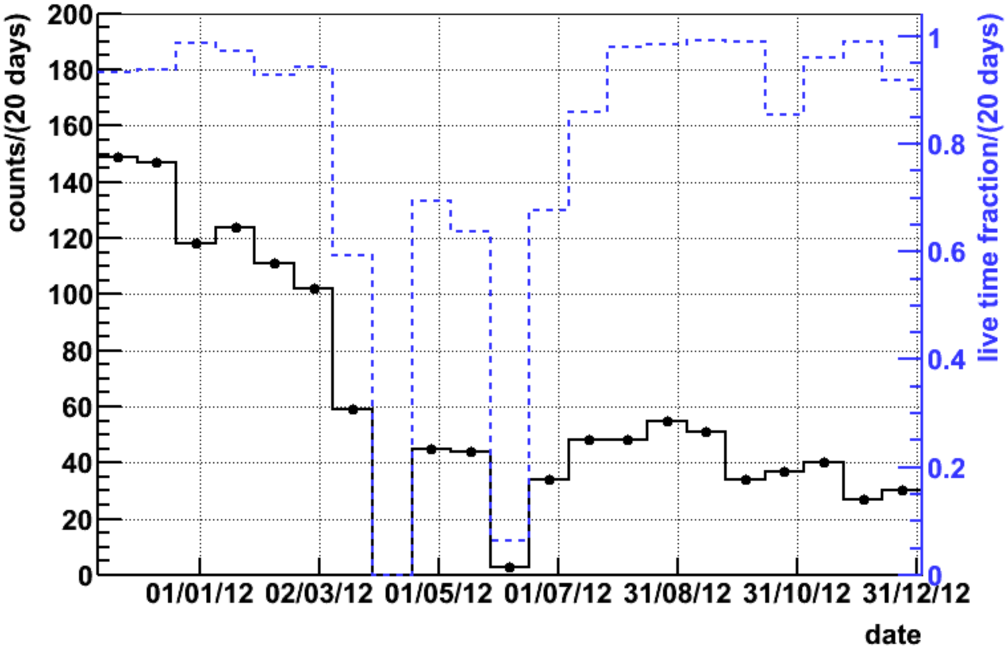
n_i : raw number of counts in i-th bin

(not scaled, not corrected for live time fraction,

λ_i : expectation in the i-th bin

corrected with the live time fraction in that bin

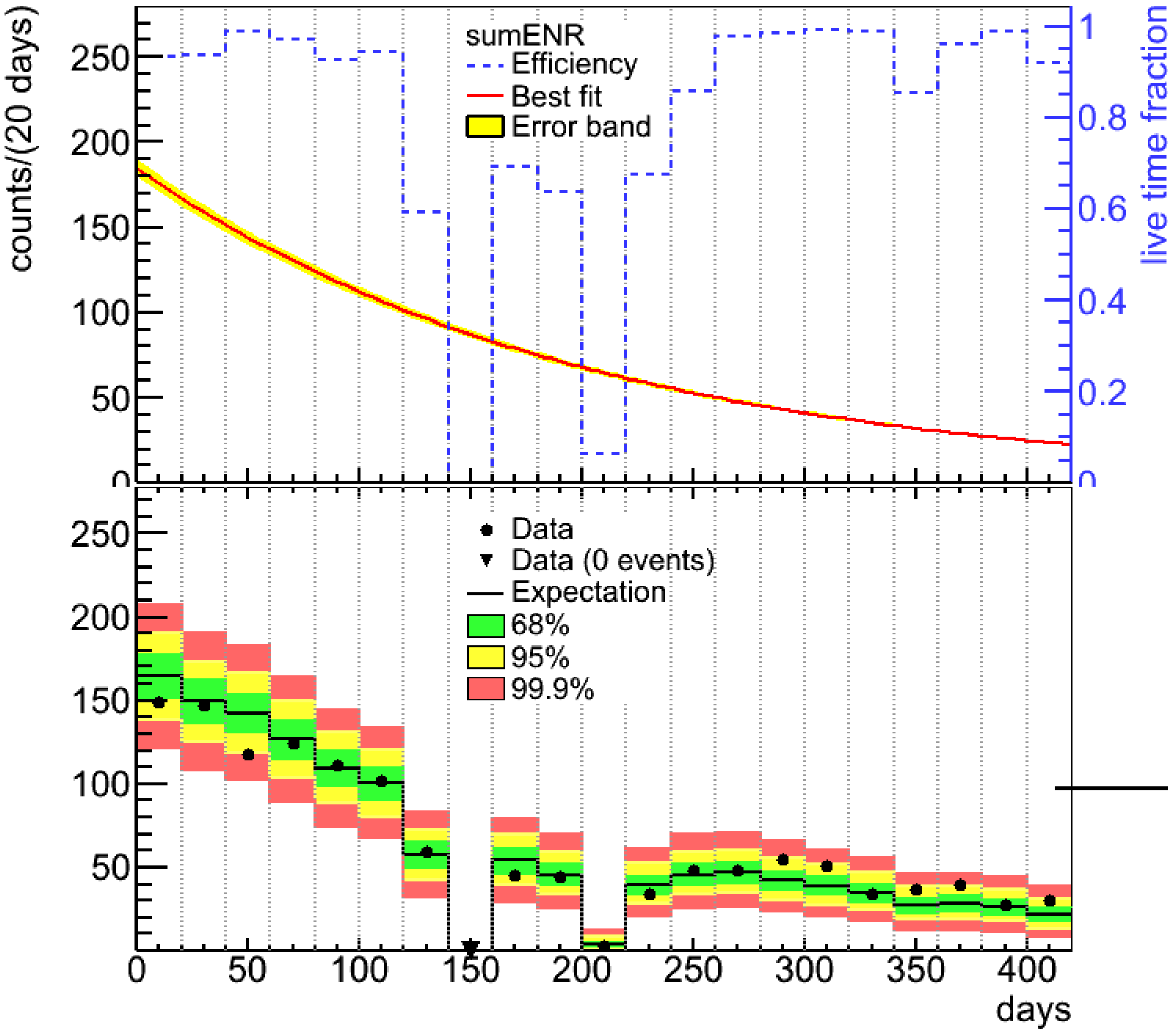
$$\boxed{\lambda_i = \epsilon_i \int_{(i-1)\Delta t}^{i\Delta t} N_0 \cdot e^{-ln2\, t/T_{1/2}}\, dt}$$



GERDA Phase I data: alpha-induced events

Event rate distribution of events with 3500 keV< E < 5300 keV in sum ^{enr}Ge-coax

Model: exponentially decaying event rate



Parameters:

N_0 = (9.26 ± 0.26) cts/day

$T_{1/2}$ = (138.4 ± 0.2) days

p-value of the fit: 0.11

Expectation

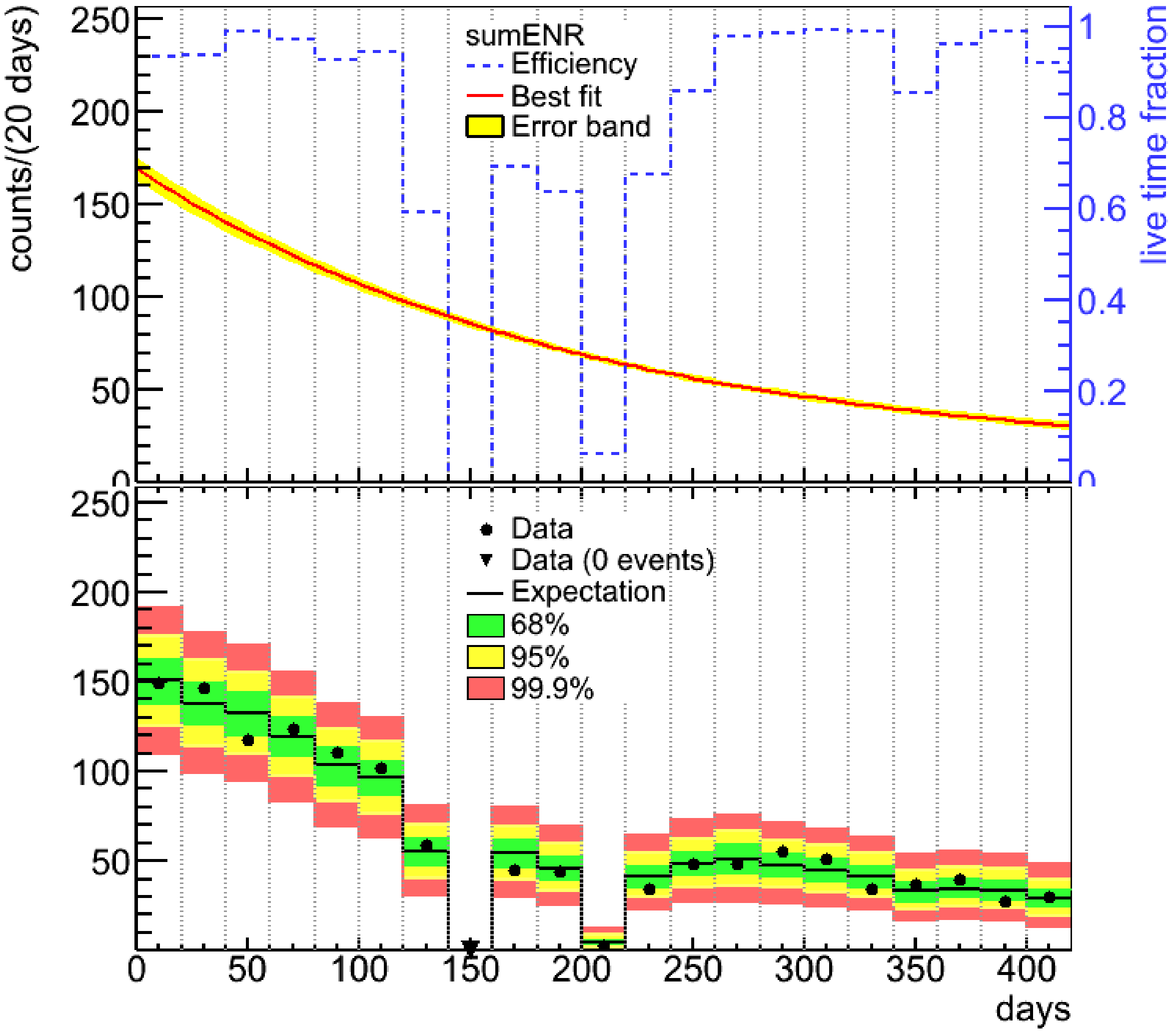
$$\lambda_i = \epsilon_i \int_{(i-1)\Delta t}^{i\Delta t} N_0 \cdot e^{-ln2\, t/T_{1/2}}\, dt$$

$$P(\vec{n}|\vec{\lambda}) = \prod_i P(n_i|\lambda_i) = \prod_i \frac{e^{-\lambda_i}\lambda_i^{n_i}}{n_i!}$$

GERDA Phase I data: alpha-induced events

Event rate distribution of events with 3500 keV< E < 5300 keV in sum ^{enr}Ge-coax

Model: exponential + constant rate



Parameters:

C = (0.57 ± 0.16) cts/day

N_0 = (7.91 ± 0.44) cts/day

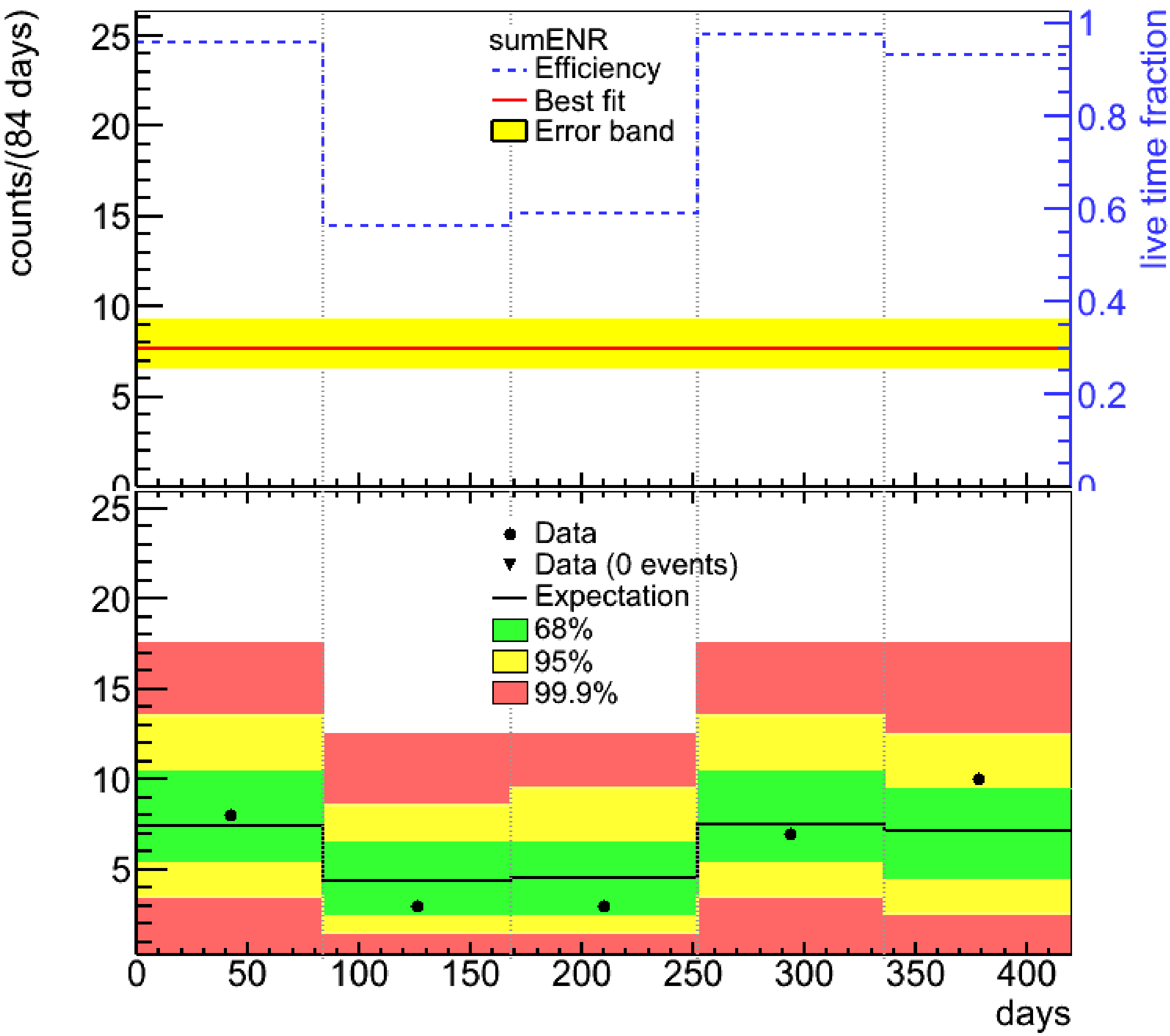
$T_{1/2}$ = (138.4 ± 0.2) days

p-value of the fit: 0.87

GERDA Phase I data: alpha-induced events

Event rate distribution of events with E > 5300 keV in sum ^{enr}Ge-coax

Model: constant rate



Parameters:

C = (0.09 ± 0.02) cts/day

p-value of the fit: 0.86