

GERDA background model

Dimitrios Palioselitis
on behalf of the GERDA collaboration

Max Planck Institute for Physics, Munich
dimitris@mpp.mpg.de

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MAX-PLANCK-GESELLSCHAFT

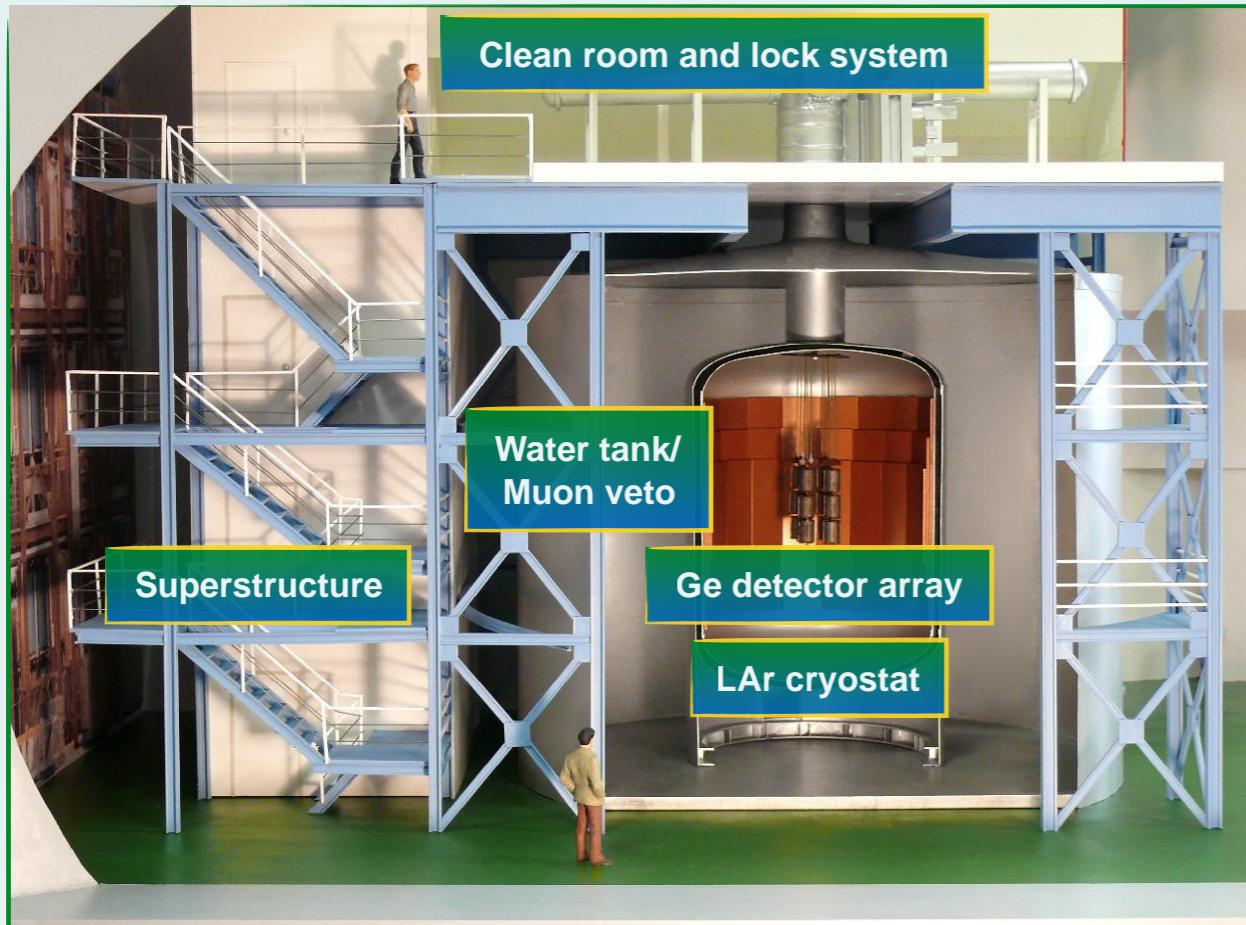


Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Outline

- GERDA overview
- background sources
- statistical analysis
- results
- cross checks
- Phase II
- summary

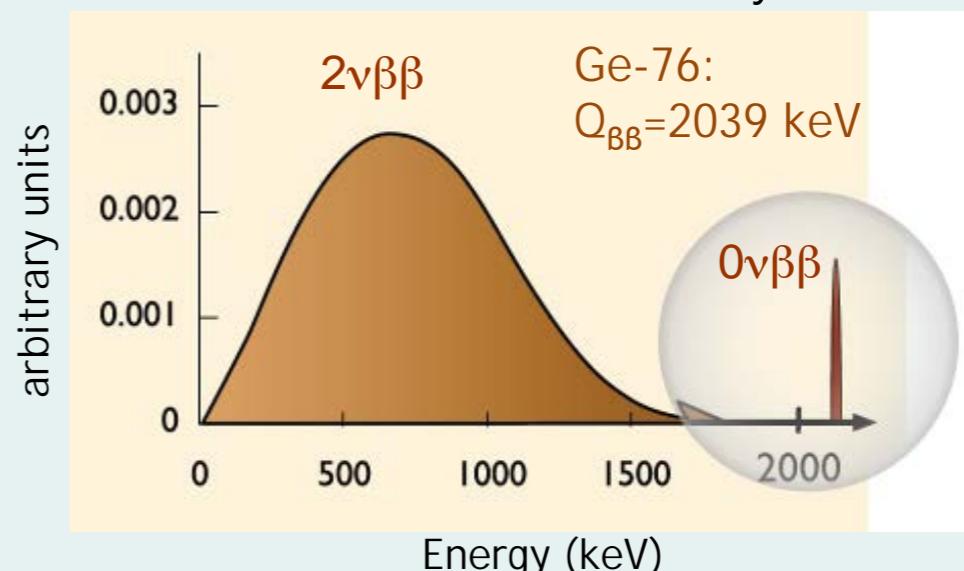
The GERDA experiment



$0\nu\beta\beta$

$$(A, Z) \rightarrow (A, Z + 2) + 2e^-$$

- lepton number violation $\Delta L=2$
- physics beyond the Standard Model
- ν have Majorana character
- mass scale and hierarchy



operation of bare Ge detectors in LAr: source=detector, reduced background from cladding material, intrinsically pure, excellent energy resolution, well-established production

GERDA Phase I is complete

- no $0\nu\beta\beta$ signal observed
- long standing claim claim strongly disfavoured
- new limit on $0\nu\beta\beta$ half-life of ^{76}Ge
 $T_{1/2} > 2.1 \times 10^{25} \text{ yr}$ (90% C.L.)

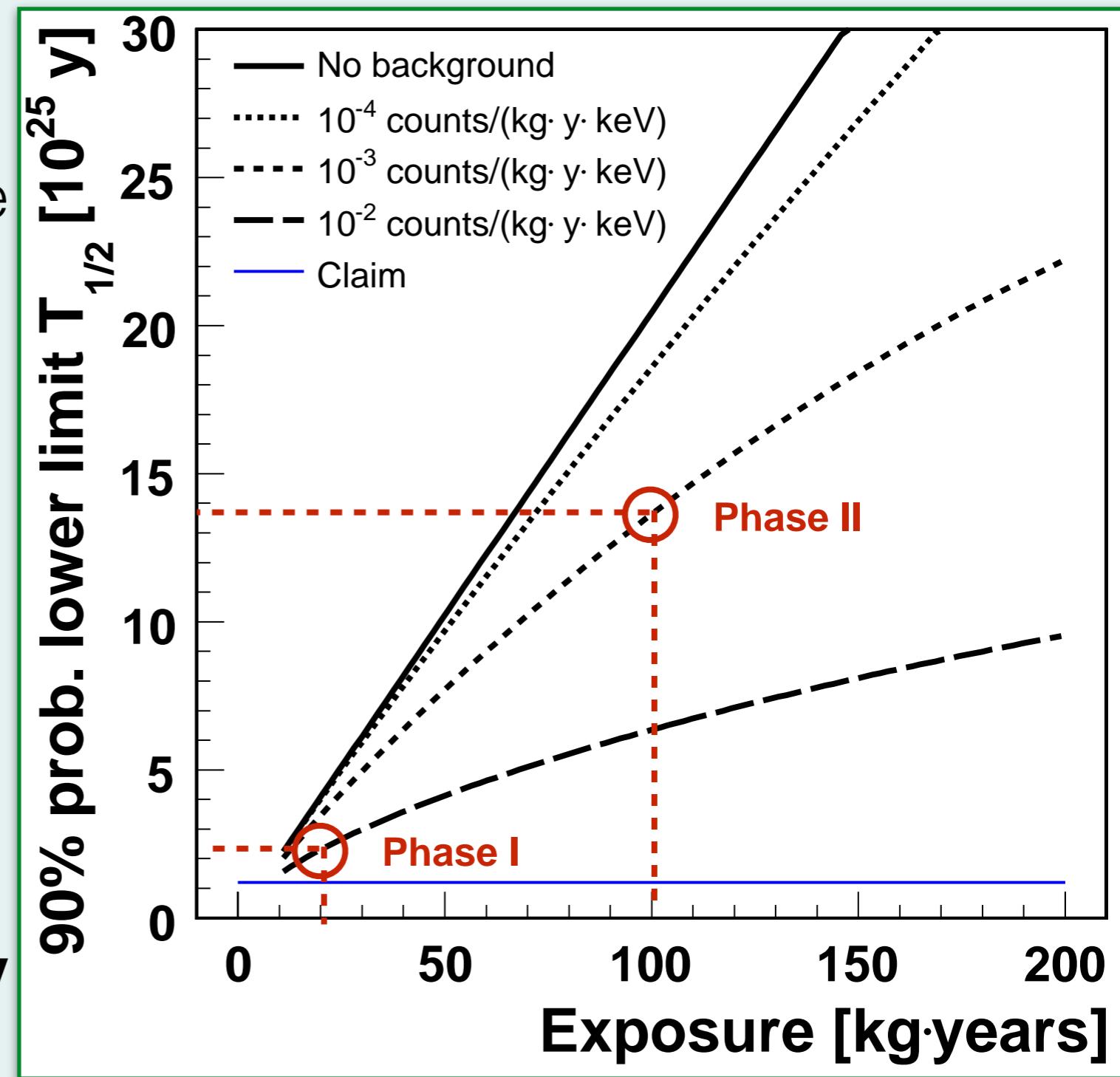
GERDA sensitivity

rare events searches:

- extremely low background
- large mass & measuring time

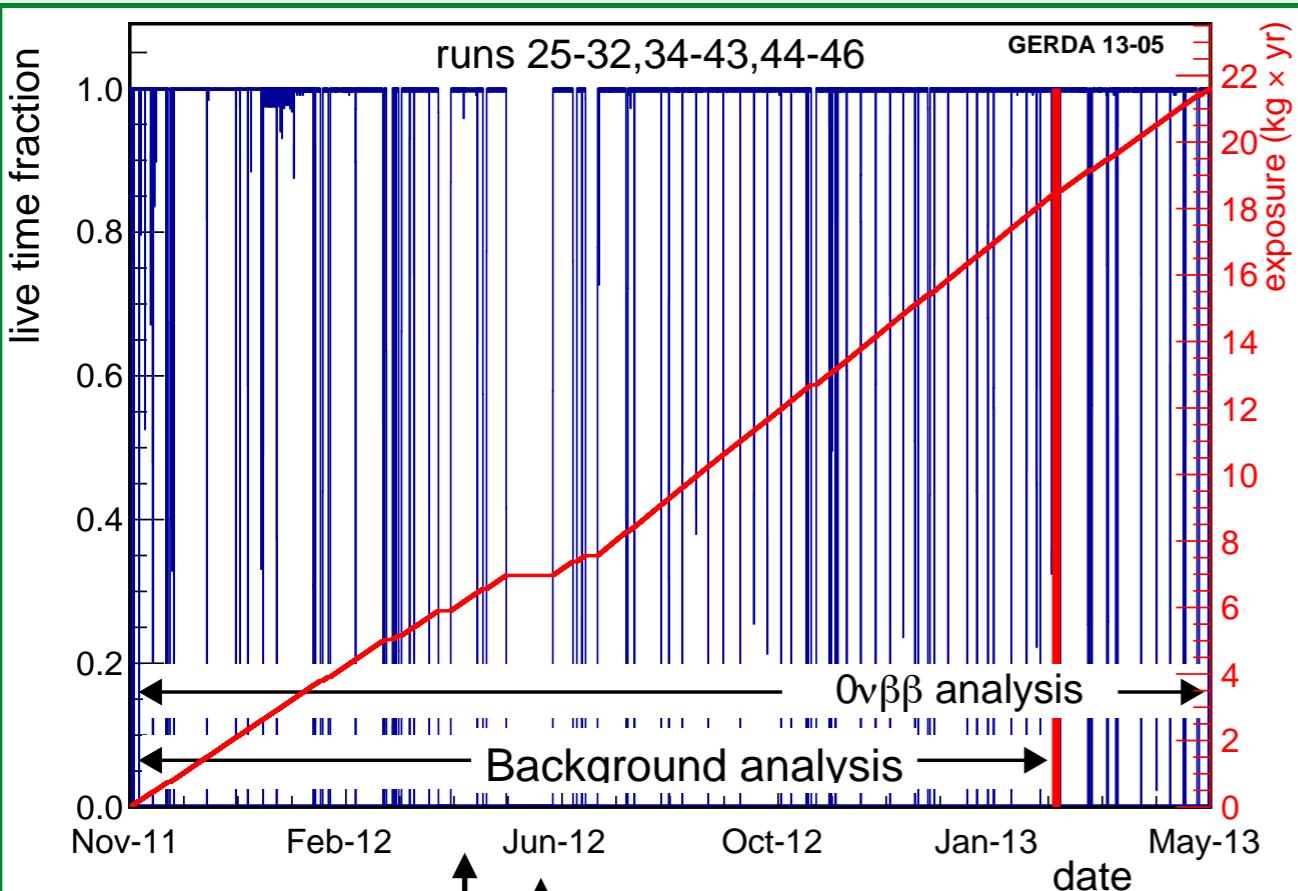
background characterisation
and suppression
necessary to achieve
higher $T_{1/2}$ sensitivity

**an order of magnitude
improvement on $T_{1/2}$ sensitivity
in ~5 years**



Phys. Rev. D75, 092003 (2006)

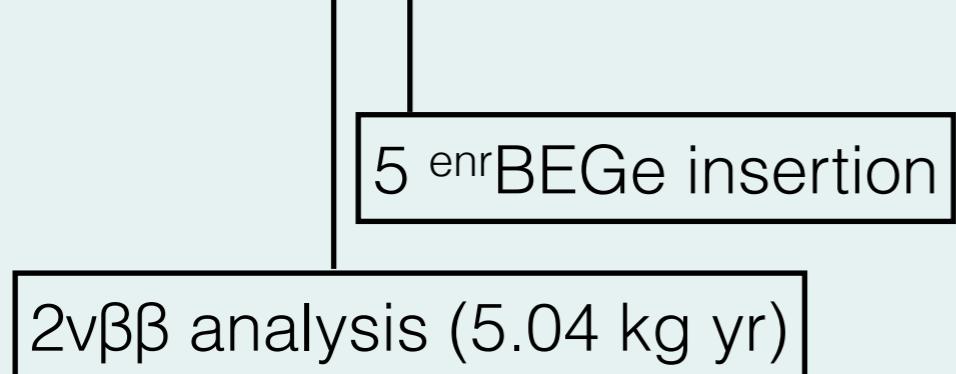
Overview of Phase I data taking



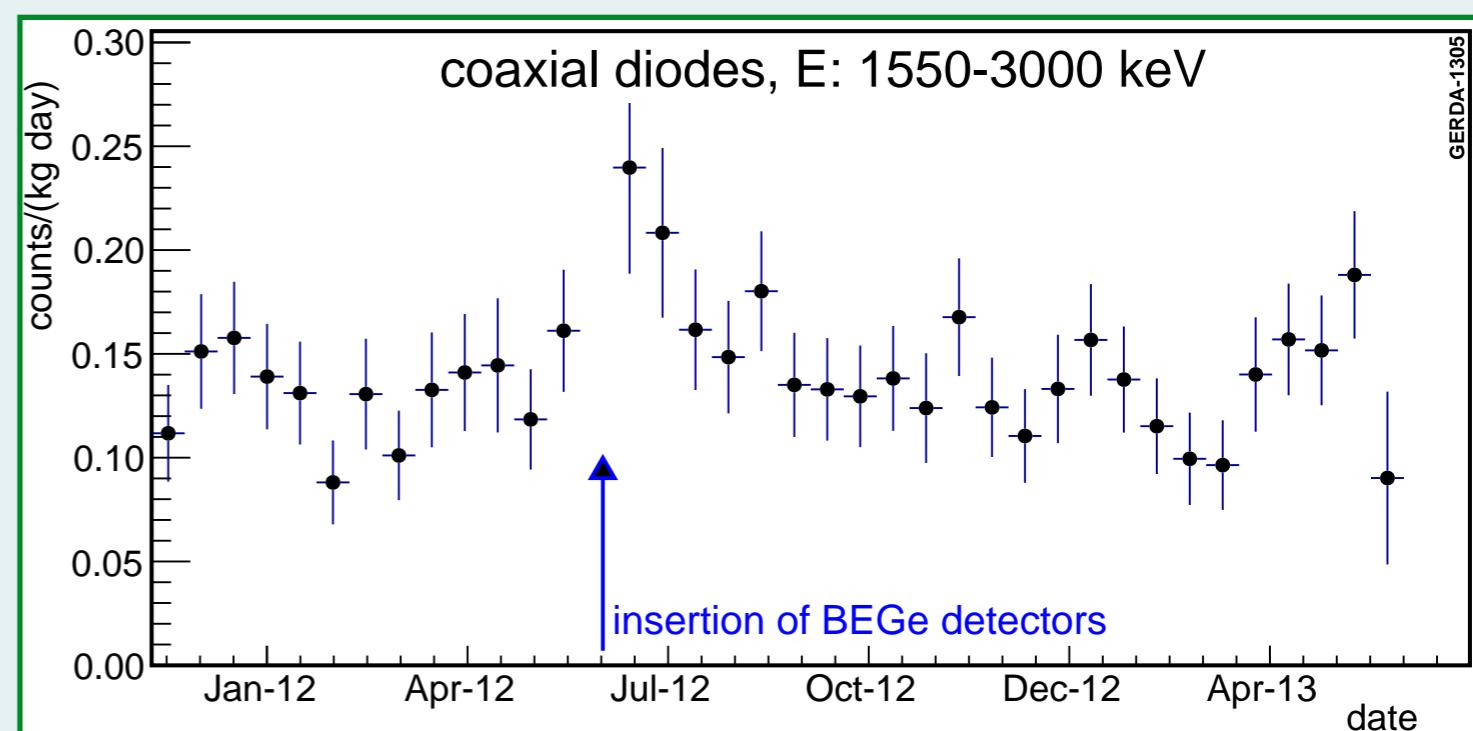
Data set	Exposure* (kg yr)
Coaxial (Golden)	17.9
Coaxial (Silver)	1.3
BEGe	2.4
Total	21.6

* total Phase-I exposure
(shorter for background analysis)

- stable background index over time
- temporary increase after BEGe detectors insertion

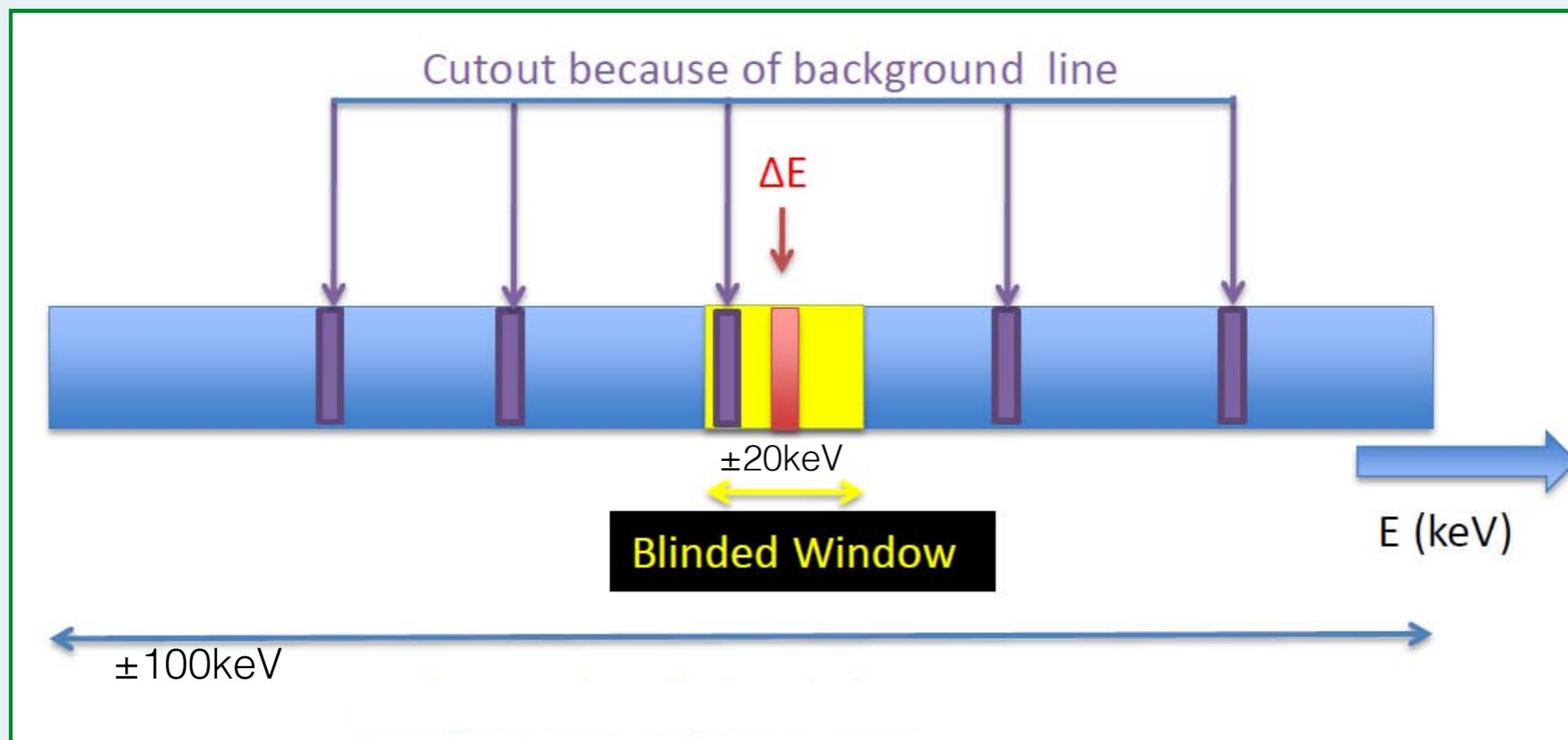


- data taking: Nov11-May13 (492 days)
- average duty cycle 88%
- bi-weekly calibration ^{228}Th ("spikes")

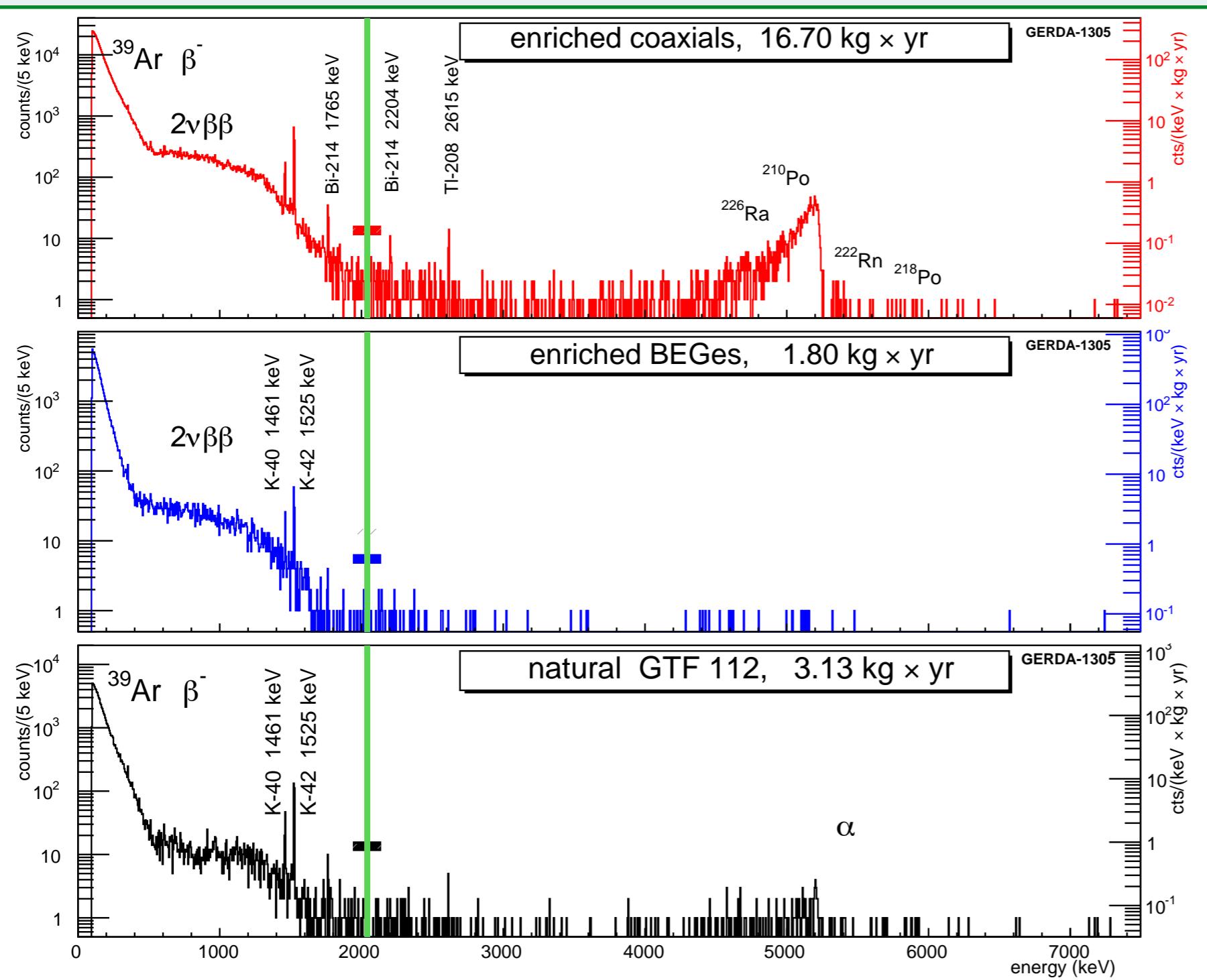


Blind analysis

- blind region: $Q_{\beta\beta} \pm 20\text{keV}$
- background model published before unblinding
- data processing, quality cuts and statistical analysis fixed prior to unblinding



Phase I energy spectrum



exposures for BG analysis

Data set	Exposure (kg yr)
Coaxial (Golden)	15.4
Coaxial (Silver)	1.3
BEGe	1.8
Total	18.5

β -induced events expected up to 3525 keV:



No contribution at $Q_{\beta\beta}$: ${}^{39}\text{Ar}$, $2\nu\beta\beta$, ${}^{40}\text{K}$, ${}^{228}\text{Ac}$
 Contribution at $Q_{\beta\beta}$: ${}^{42}\text{K}$ (${}^{42}\text{Ar}$), ${}^{214}\text{Bi}$ (${}^{238}\text{U}$), ${}^{208}\text{Tl}$ (${}^{232}\text{Th}$), ${}^{60}\text{Co}$, α events

Screening results

Component	Units	^{40}K	^{214}Bi and ^{226}Ra	^{228}Th	^{60}Co	^{222}Rn	BI [10^{-3} cts/(keV kg yr)]
<i>Close sources: up to 2 cm from detectors</i>							
Copper det. support	$\mu\text{Bq}/\text{det.}$	<7	<1.3	<1.5			<0.2
PTFE det. support	$\mu\text{Bq}/\text{det.}$	6.0 (11)	0.25 (9)	0.31 (14)			0.1
PTFE in array	$\mu\text{Bq}/\text{det.}$	6.5 (16)	0.9 (2)				0.1
Mini shroud	$\mu\text{Bq}/\text{det.}$		22 (7)				2.8
Li salt	mBq/kg		17 (5)				$\approx 0.003^{\text{a}}$
<i>Medium distance sources: 2–30 cm from detectors</i>							
CC2 preamps	$\mu\text{Bq}/\text{det.}$	600 (100)	95 (9)	50 (8)			0.8
Cables and suspension	mBq/m	1.40 (25)	0.4 (2)	0.9 (2)	76 (16)		0.2
<i>Distant sources: further than 30 cm from detectors</i>							
Cryostat	mBq					54.7 (35)	<0.7
Copper of cryostat	mBq	<784	264 (80)	216 (80)	288 (72)		<0.05
Steel of cryostat	kBq	<72	<30	<30	475		
Lock system	mBq					2.4 (3)	<0.03
^{228}Th calib. source	kBq			20			<1.0

^a Value derived for 1 mg of Li salt absorbed into the surface of each detector

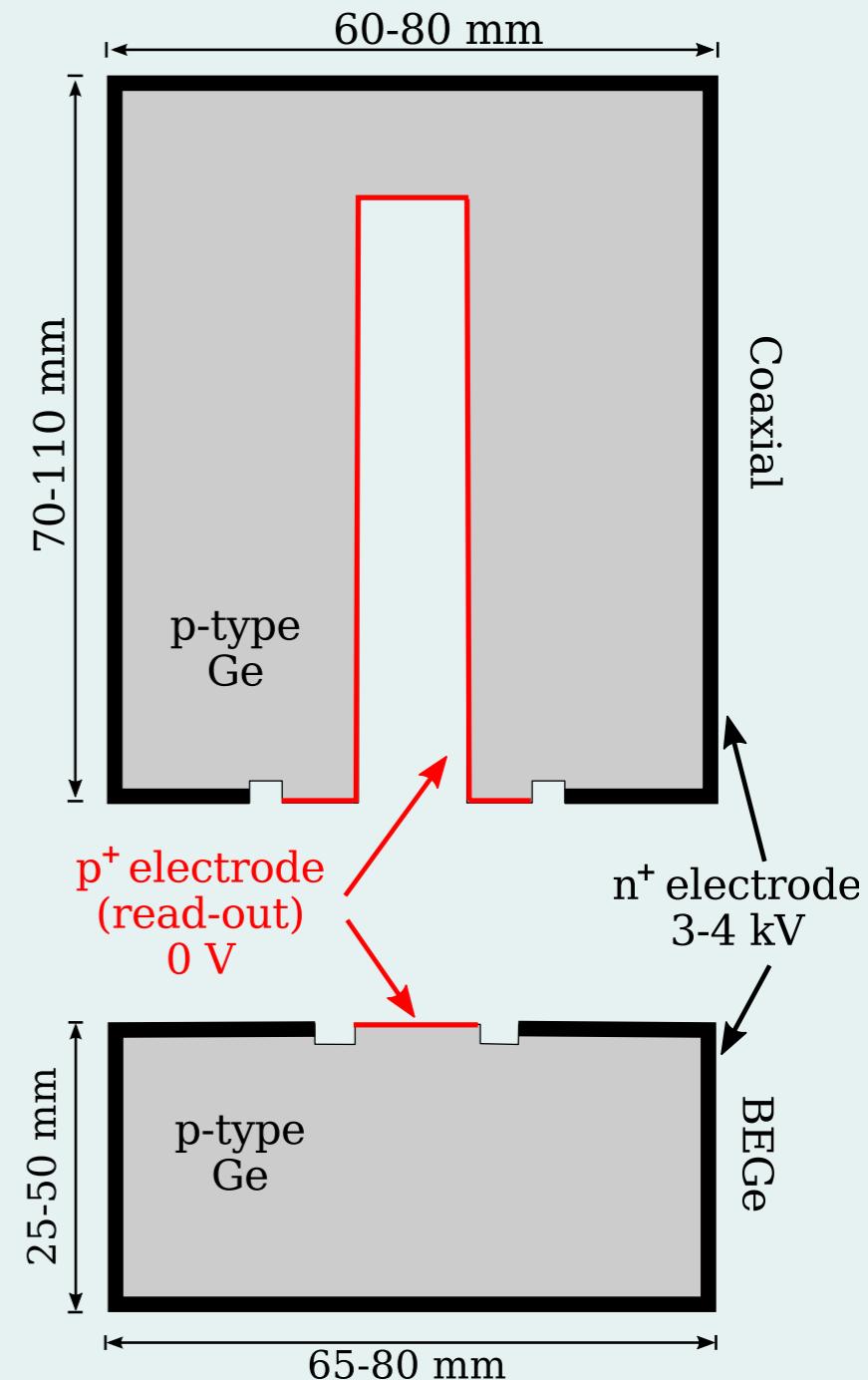
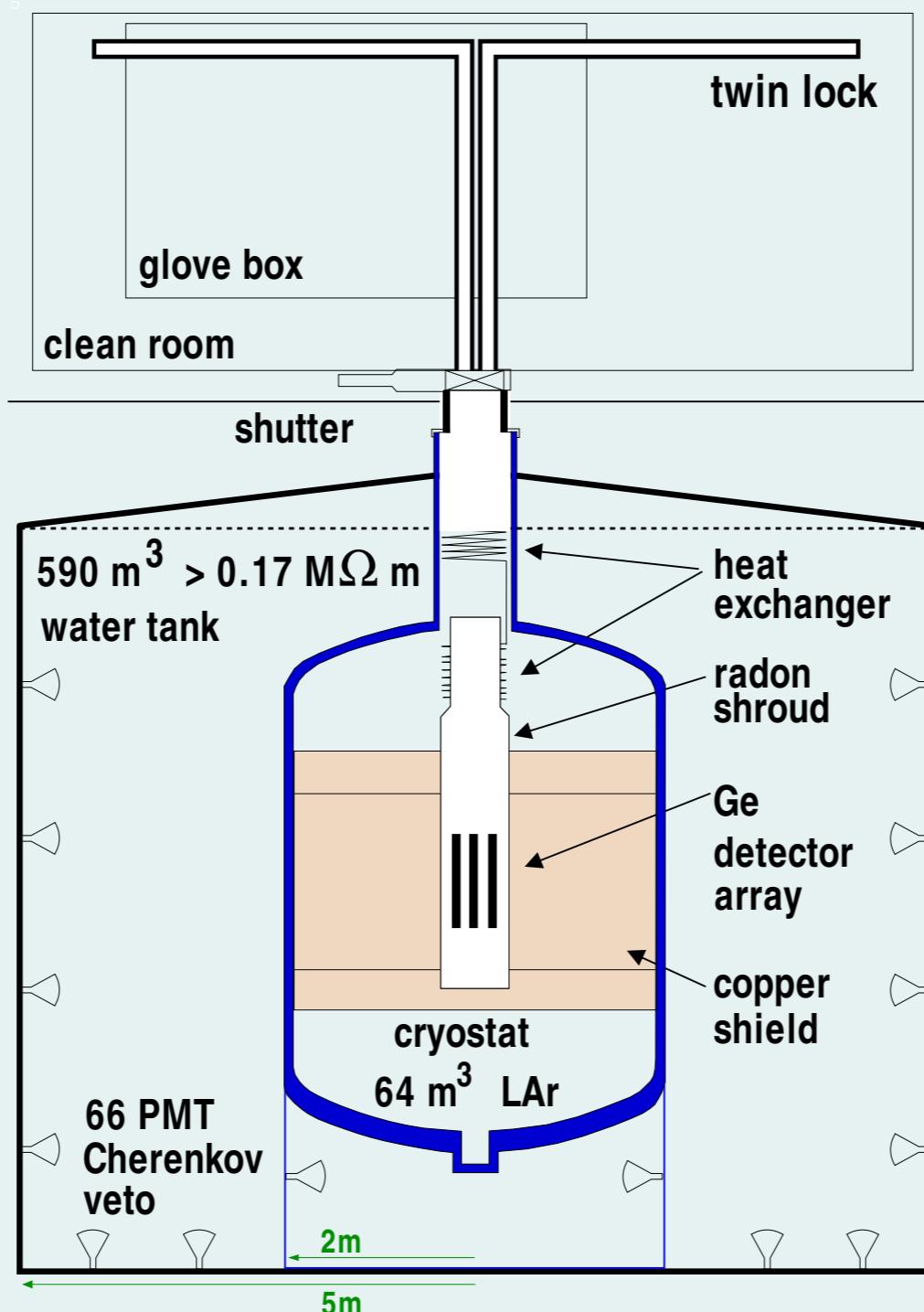
- hardware components tested for radio-purity prior to installation
- radon shroud around the array to keep ^{222}Rn in LAr away from detectors

expected BI contributions (cts/keV kg yr)

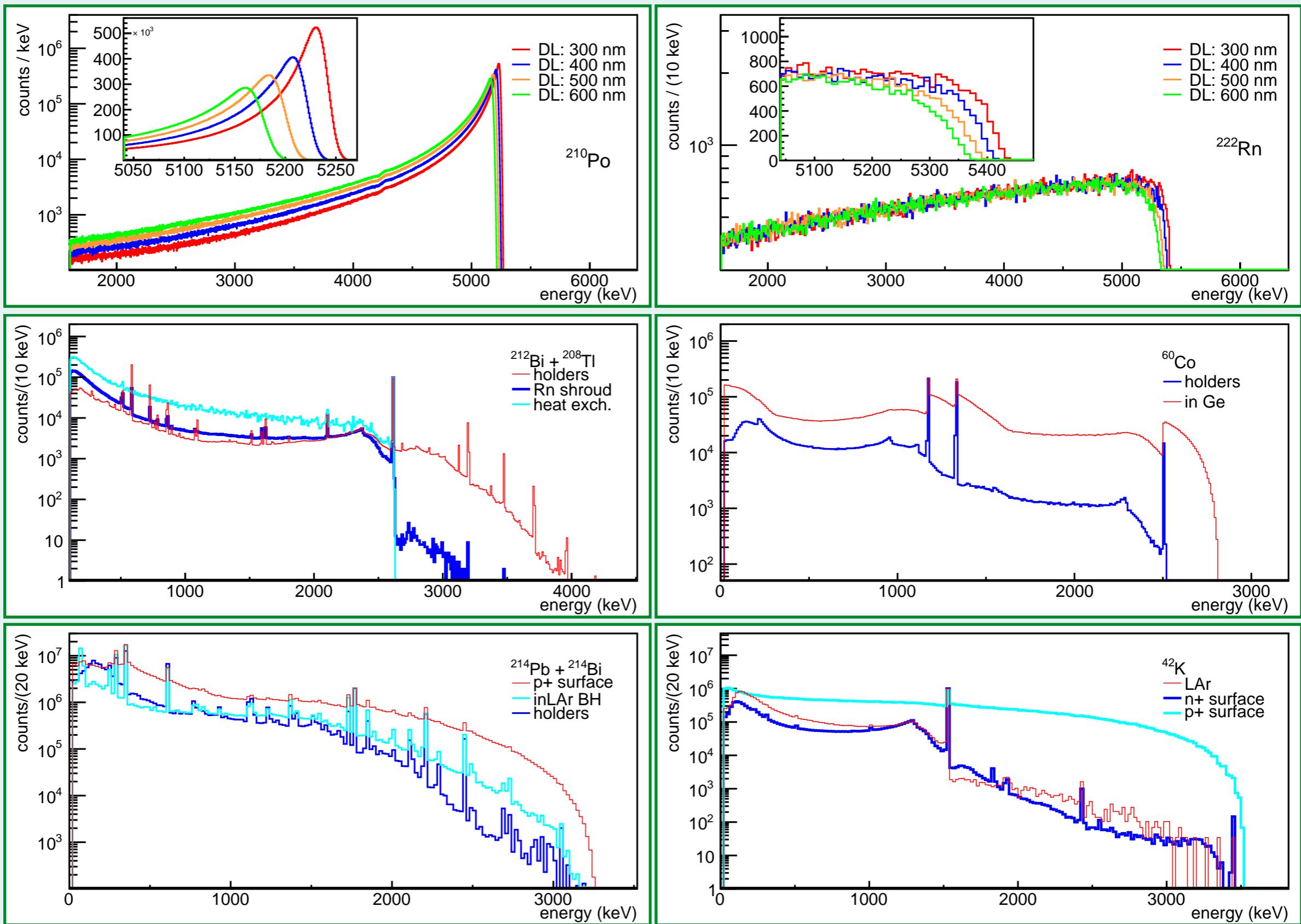
close (<2cm) $\sim 3 \cdot 10^{-3}$, medium (2-30 cm) $\sim 10^{-3}$, far (>30cm) $< 10^{-3}$

Simulation of background sources

Source	Location
^{210}Po	p ⁺ surface
^{226}Ra chain	p ⁺ surface
^{222}Rn chain	LAr in bore hole
^{214}Bi and ^{214}Pb	n ⁺ surface Mini shroud Detector assembly p ⁺ surface Radon shroud
^{208}Tl and ^{212}Bi	LAr close to p ⁺ surface Detector assembly Radon shroud Heat exchanger
^{228}Ac	Detector assembly Radon shroud
^{42}K	Homogeneous in LAr n ⁺ surface p ⁺ surface
^{60}Co	Detectors Detector assembly
$2\nu\beta\beta$	Detectors
^{40}K	Detector assembly



Simulation of background sources



Statistical analysis

Posterior probability:

$$P(\vec{\lambda}|\vec{n}) = \frac{P(\vec{n}|\vec{\lambda})P_0(\vec{\lambda})}{\int P(\vec{n}|\vec{\lambda})P_0(\vec{\lambda})d\vec{\lambda}}$$

Likelihood:

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

expected number of events in bin i
for model components M :

$$\lambda_i = \sum_M \lambda_{i,M}$$

expectation from model component M
in the i-th bin :

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

- **Maximise posterior probability**

Markov Chain Monte Carlo
in Bayesian Analysis Toolkit (BAT)
A. Caldwell et. al.,
Comput. Phys. Commun. 180, 2197 (2009)

- **Fit 3.5 - 7.5 MeV spectrum first**

determine a-contribution

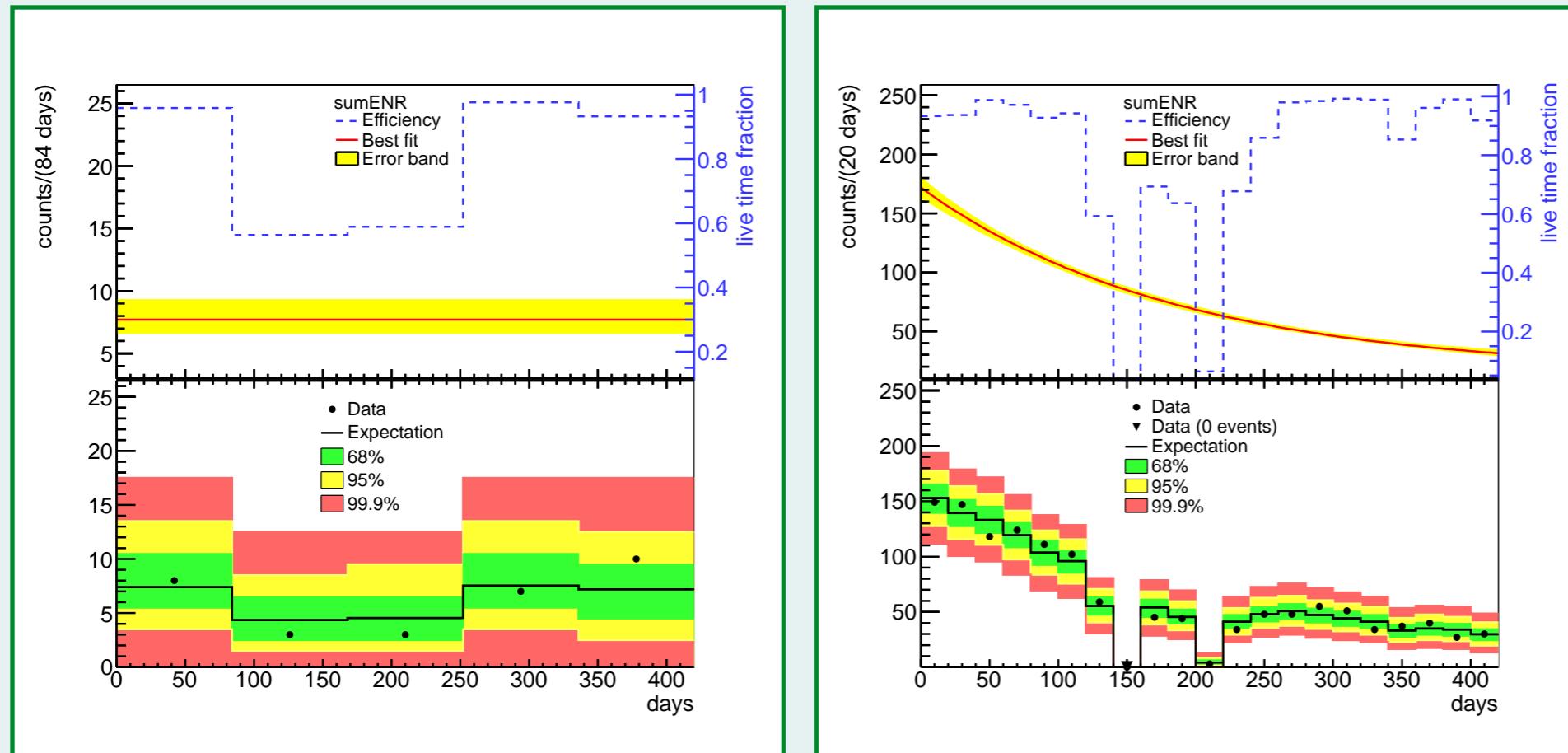
- **Fit 570 - 7500 keV range**

a-spectrum best fit and other
background components

- **Two models constructed:**

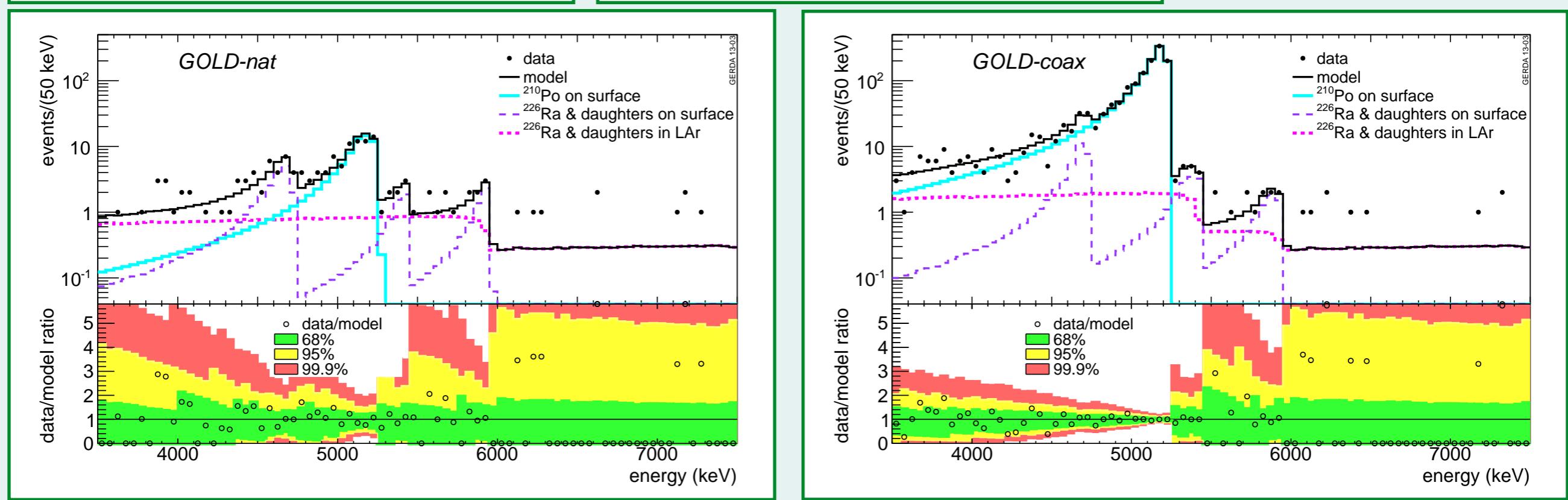
- *Minimum model*
only well motivated close sources
- *Maximum model*
additional medium and
far distance sources

a-spectrum fit

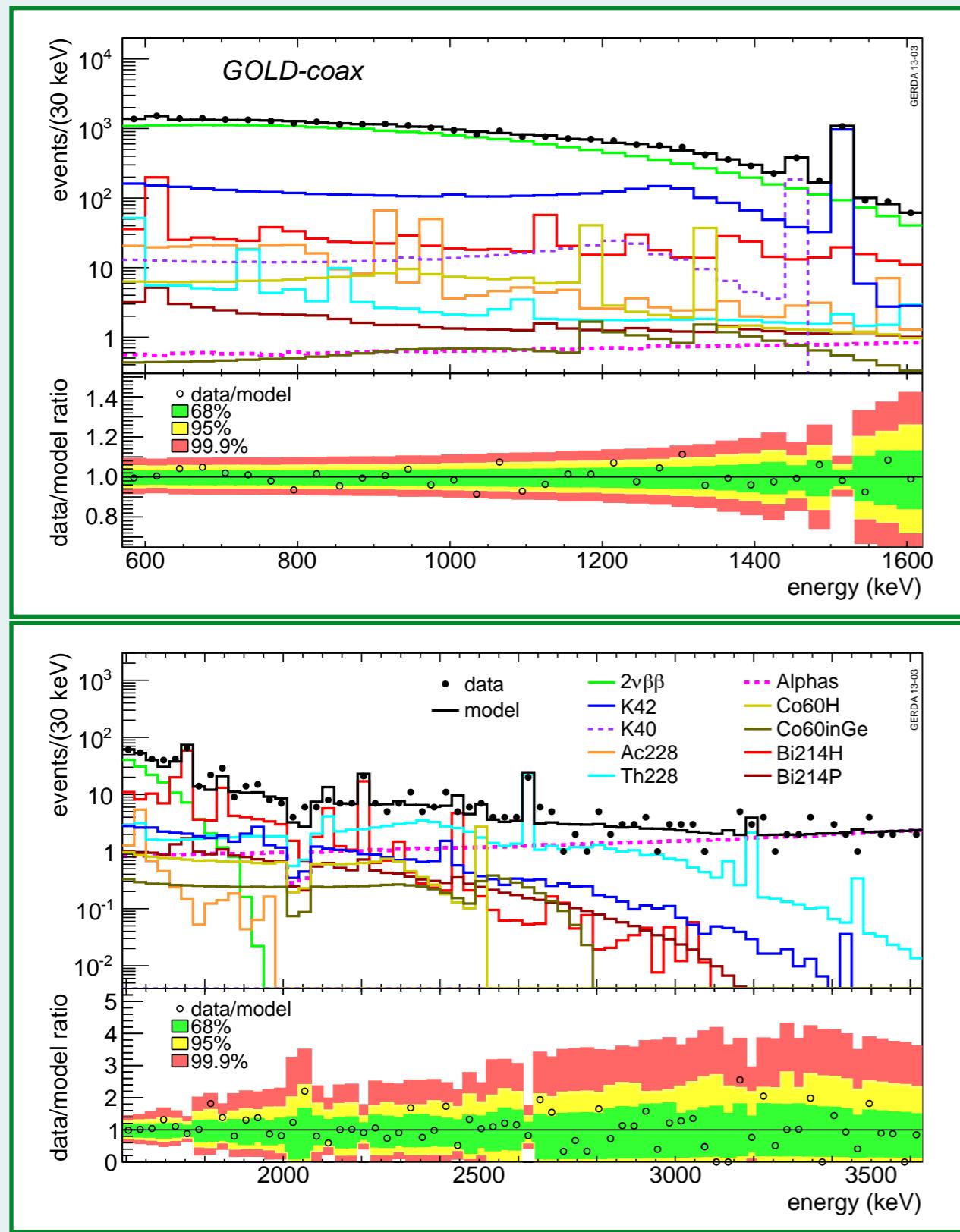


3.5 - 5.3 MeV
exponential +
constant event rate

5.3 - 7.5 MeV
constant event rate



Background decomposition (enriched coaxial detectors)

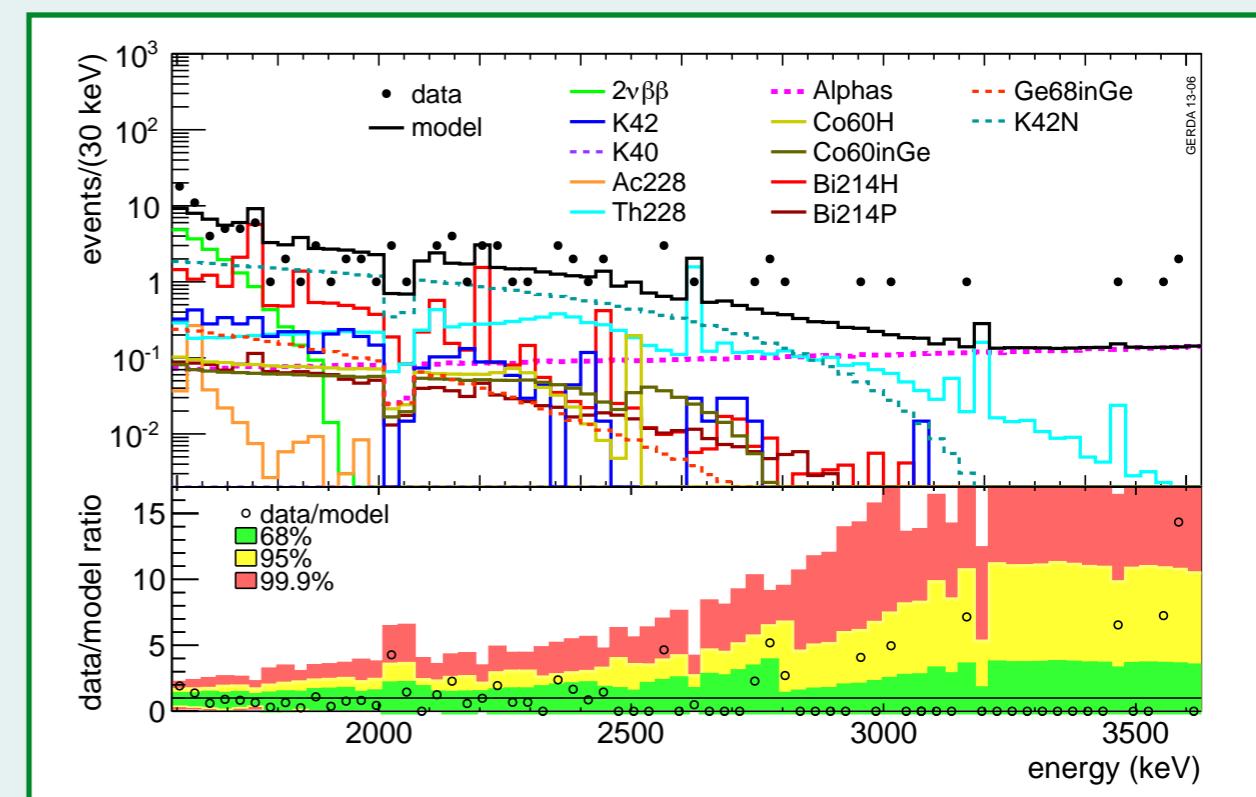
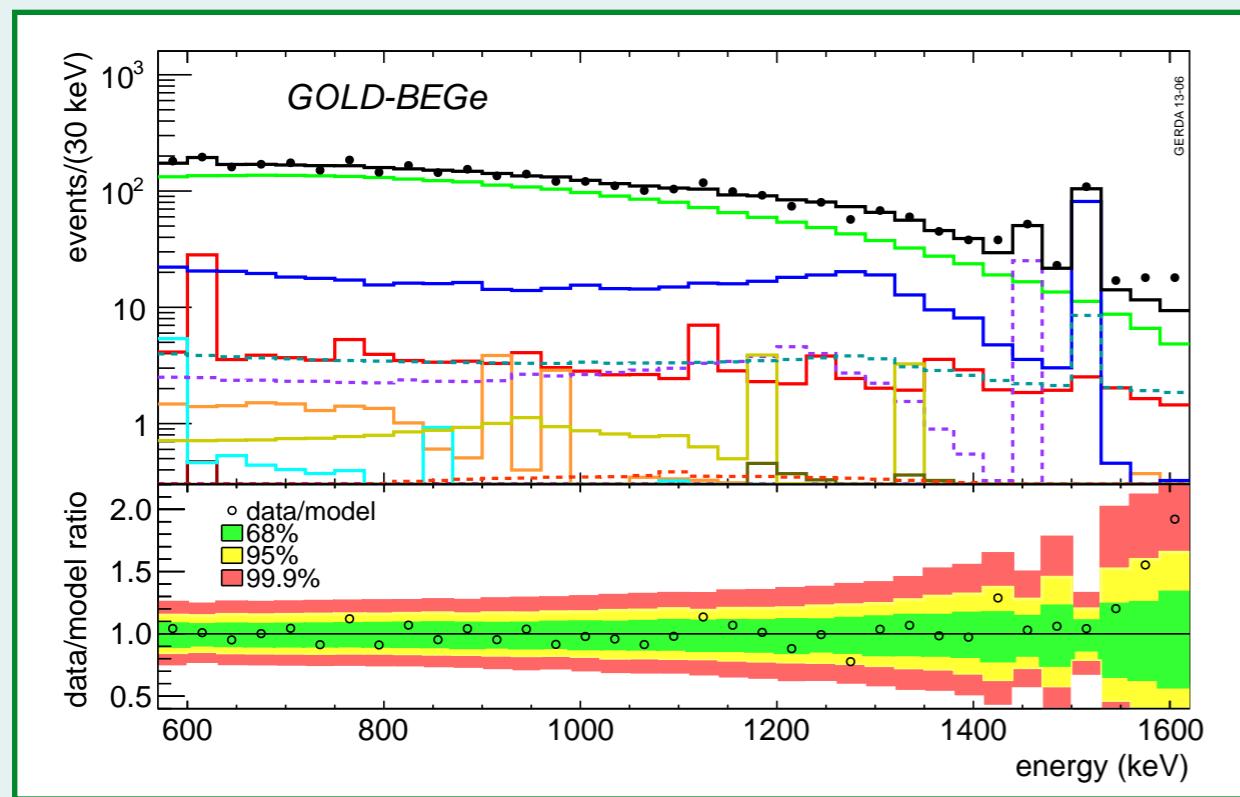
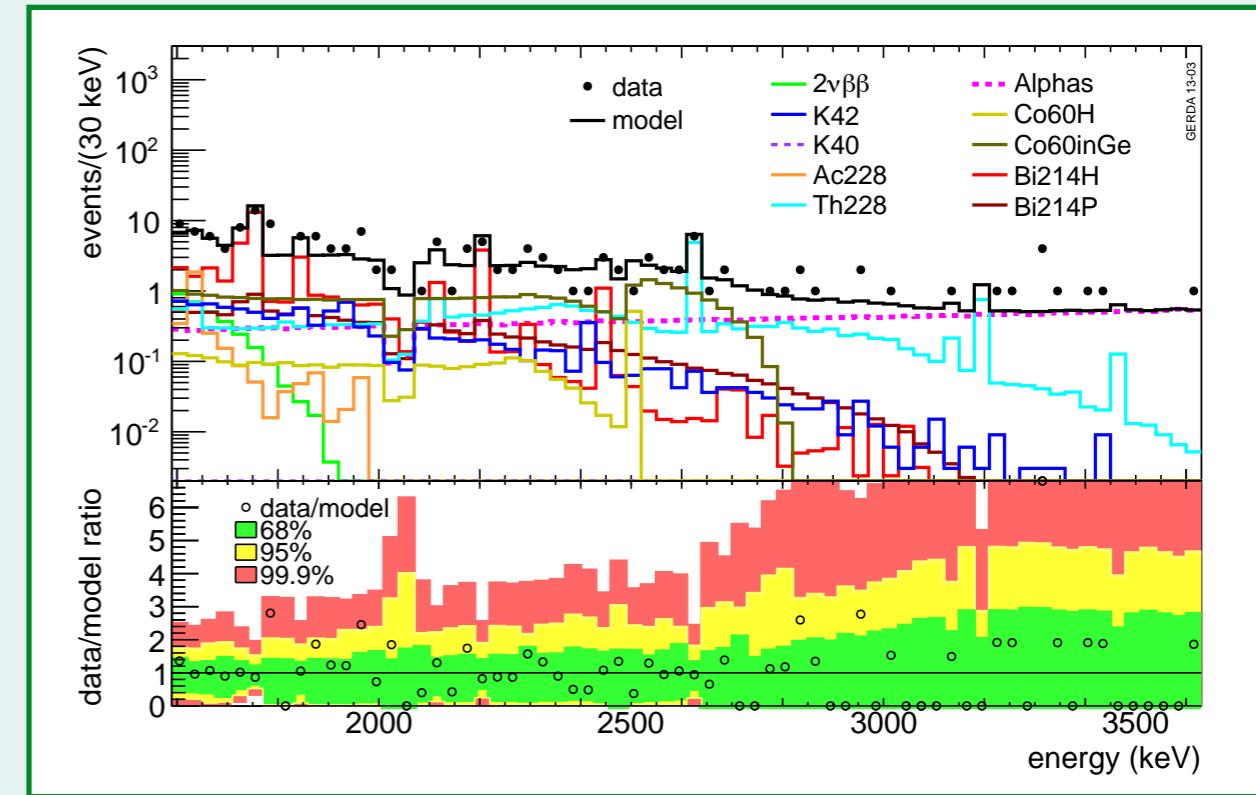
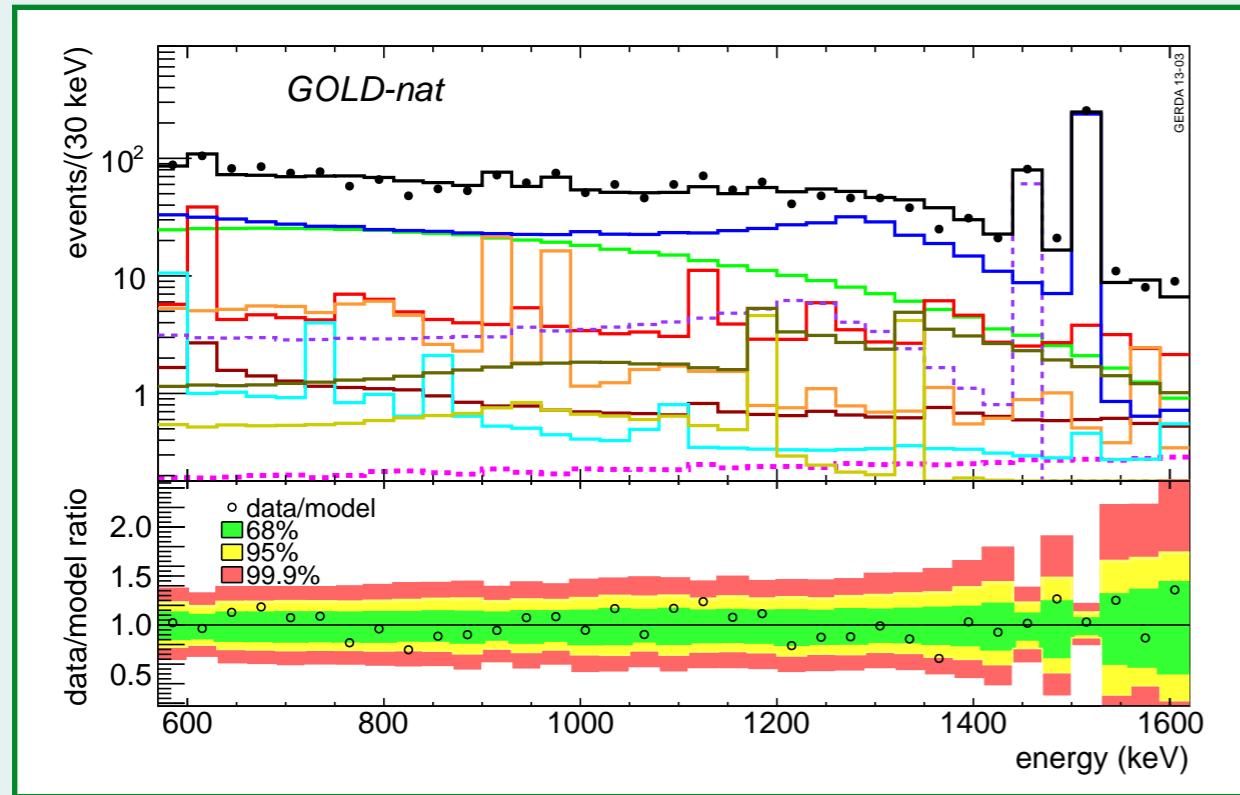


spectral fit with simulated spectra
(570 - 7500 keV, blind at $Q_{\beta\beta} \pm 20$ keV)

Contributions at $Q_{\beta\beta}$

- β/γ induced events from:
 - ^{42}K ($Q = 3.5$ MeV)
 - ^{60}Co ($Q = 2.8$ MeV)
 - ^{214}Bi (^{238}U) & ^{208}TI (^{228}Th)
- α events from:
 - surface contamination
 - degraded ^{222}Rn in LAr

Background decomposition (BEGe and natural detectors)



Activities

Source	Location	Units	<i>GOLD-coax</i>		<i>GOLD-nat</i>	<i>GOLD-coax</i>
			Minimum	Maximum	Minimum	Coincident
$^{40}\text{K}^{\text{c}}$	det. assembly	$\mu\text{Bq}/\text{det.}$	152 [136, 174]	151 [136, 174]	218 [188, 259]	252 [164, 340]
$^{42}\text{K}^{\text{c}}$	LAr	$\mu\text{Bq}/\text{kg}$	106 [103, 111]	91 [72, 99]	98.3 [92, 108]	168 [150, 186]
$^{42}\text{K}^{\text{c}}$	p^+ surface	μBq		11.6 [3.1, 18, 3]		
$^{42}\text{K}^{\text{c}}$	n^+ surface	μBq		4.1 [1, 2, 8.5]		
$^{60}\text{Co}^{\text{c}}$	det. assembly	$\mu\text{Bq}/\text{det.}$	4.9 [3.1, 7.3]	3.2 [1.6, 5.6]	2.6 [0, 6.0]	5.0 [2.5, 7.5] ^b
$^{60}\text{Co}^{\text{c}}$	Germanium	μBq	>0.4 ^a	>0.2 ^a	6 [3.0, 8.4]	
$^{214}\text{Bi}^{\text{c}}$	det. assembly	$\mu\text{Bq}/\text{det.}$	35 [31, 39]	15 [3.7, 21.1]	34.1 [27.3, 42.1]	40 [28, 52]
$^{214}\text{Bi}^{\text{c}}$	LAr close to p^+	$\mu\text{Bq}/\text{kg}$		<299.5		
$^{214}\text{Bi}^{\text{m}}$	Radon shroud	mBq		<49.9		
$^{214}\text{Bi}^{\text{c}}$	p^+ surface	μBq	2.9 [2.3, 3.9] ^a	3.0 [2.1, 4.0] ^a	1.6 [1.2, 2.1] ^a	
$^{228}\text{Th}^{\text{c}}$	det. assembly	$\mu\text{Bq}/\text{det.}$	15.1 [12.7, 18.3]	5.5 [1.8, 8.8]	15.7 [10.0, 25.0]	9.4 [7.9, 10.9]
$^{228}\text{Ac}^{\text{c}}$	det. assembly	$\mu\text{Bq}/\text{det.}$	17.8 [10.0, 26.8]	<15.7	25.9 [16.7, 36.7]	33 [18, 48]
$^{228}\text{Th}^{\text{m}}$	Radon shroud	mBq		<10.1		
$^{228}\text{Ac}^{\text{m}}$	Radon shroud	mBq		91.5 [27, 97]		
$^{228}\text{Th}^{\text{f}}$	Heat exchanger	Bq		<4.1		

- Both minimum and maximum models describe the observed spectrum well
- Most significant contribution from close sources (p^+/n^+ surfaces)
- All components expected from screening are observed

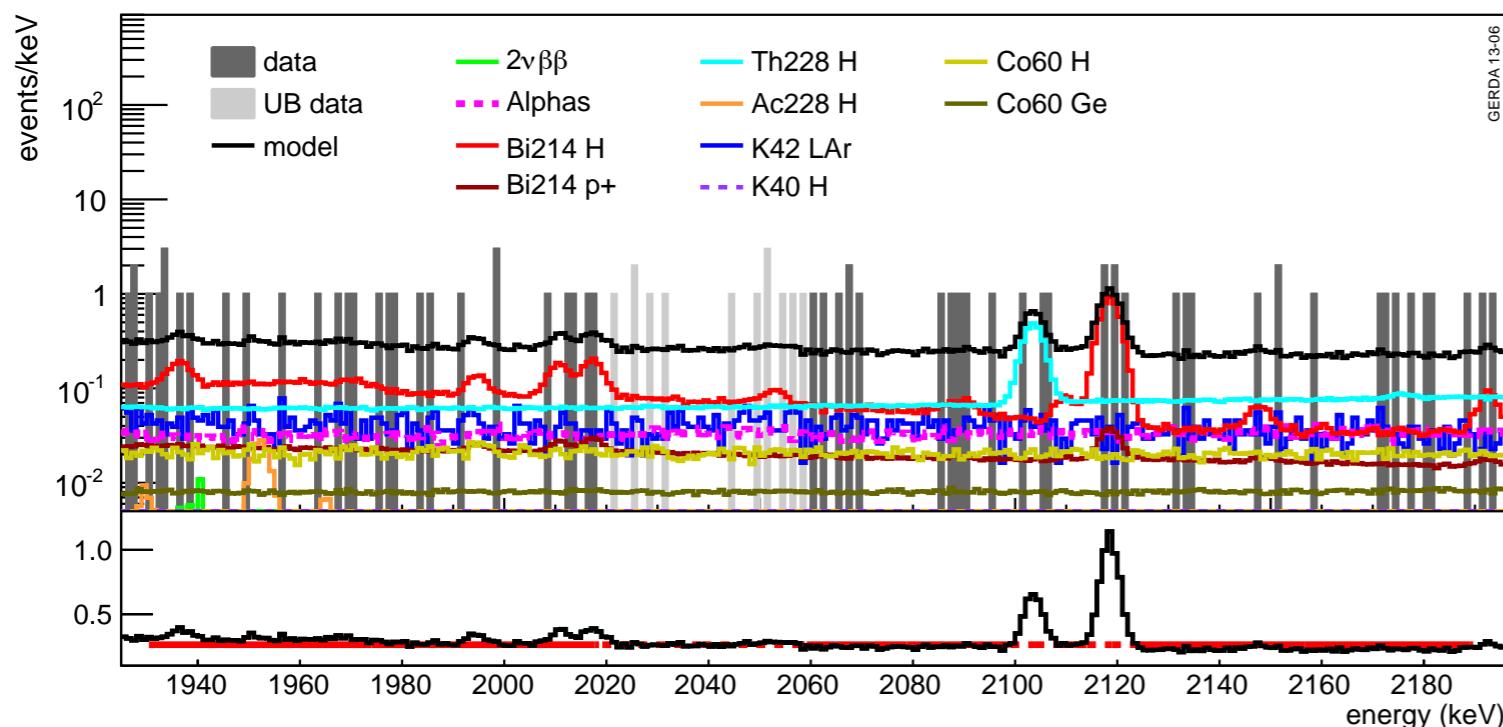
Cross checks



- Extracted $2\nu\beta\beta$ *half-life* from fit results is consistent with previous dedicated analysis
(J. Phys. G 40 (2013) 035110)
- Excellent agreement of γ -lines count rates between model results and data
- Fit is stable under different *binning choices* and individual *background component assumptions* (10% variation of background index in $Q_{\beta\beta}$ region)
- Consistent number of *BiPo coincidences* between model and data
- Consistent number of *p+ surface events*
- Consistency in derived *activities for coincidence spectra*

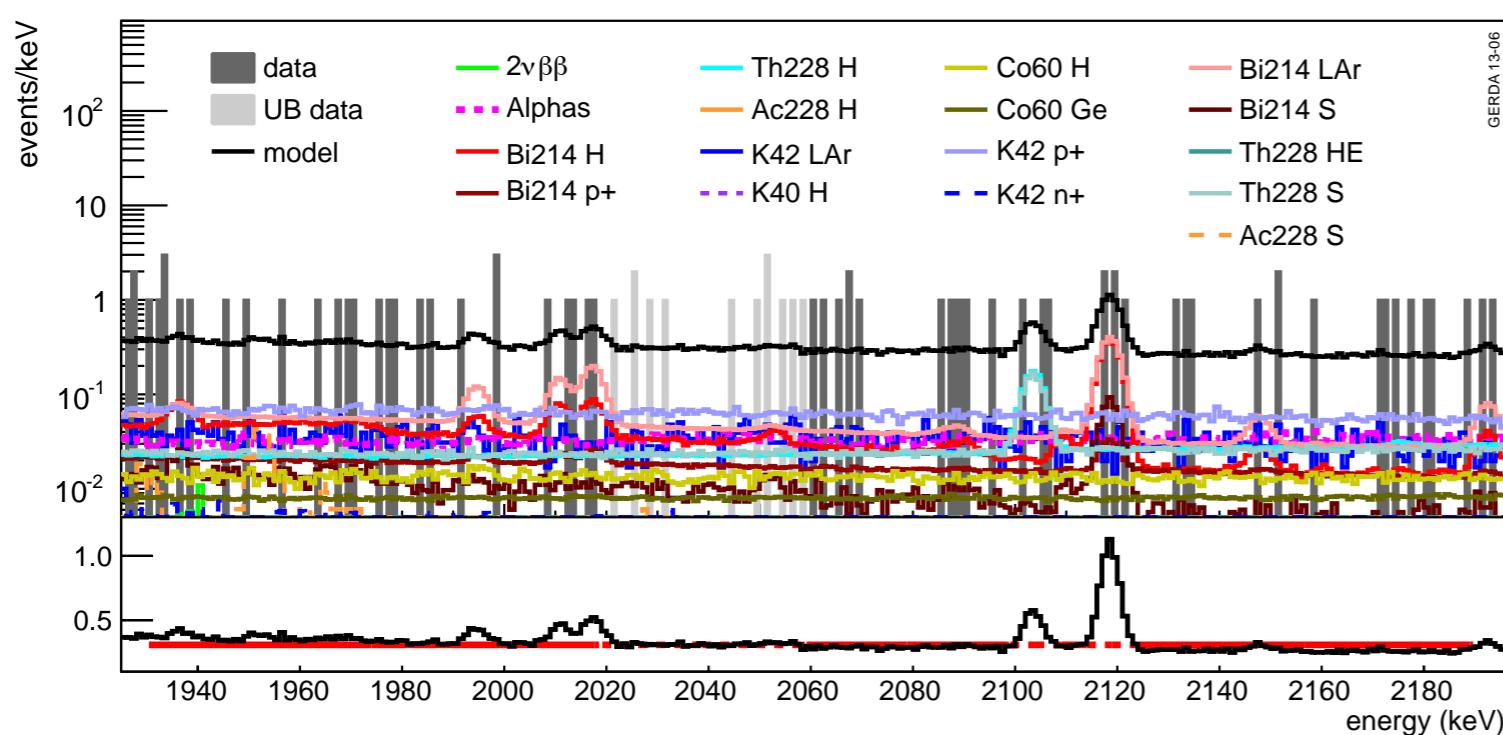
Background Index at $Q_{\beta\beta}$

Minimal model (well-motivated contributions)

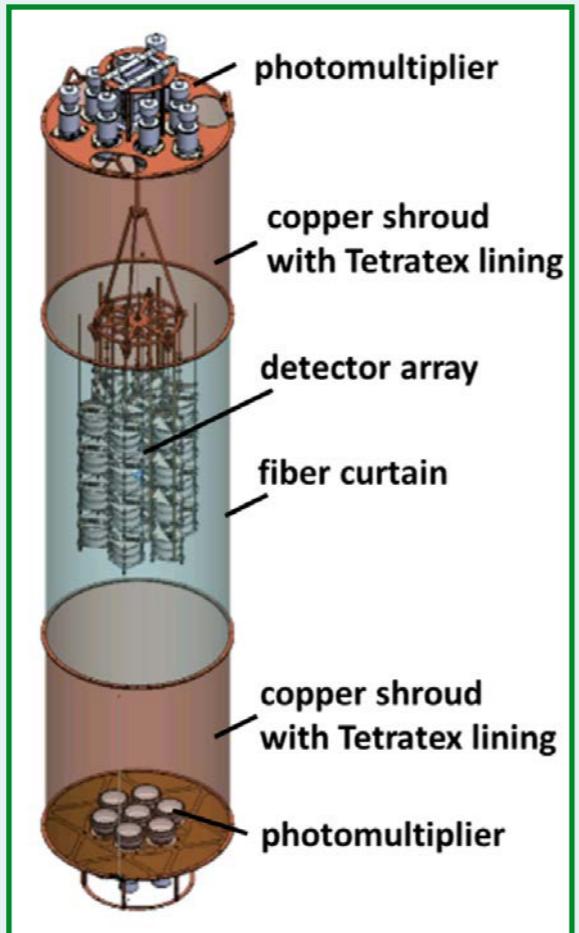


- no γ line expected around $Q_{\beta\beta}$
- agreement after partial unblinding
- spectrum can be modelled with flat background (1930-2190 keV) excluding ^{214}Bi (2104 keV) and ^{208}Tl (2119 keV)
- background index at $Q_{\beta\beta}$ (no PSD) $(17.6\text{-}23.8)\times 10^{-3}$ cts/(keV kg yr)

Maximum model (additional contributions)



Phase II LAr instrumentation



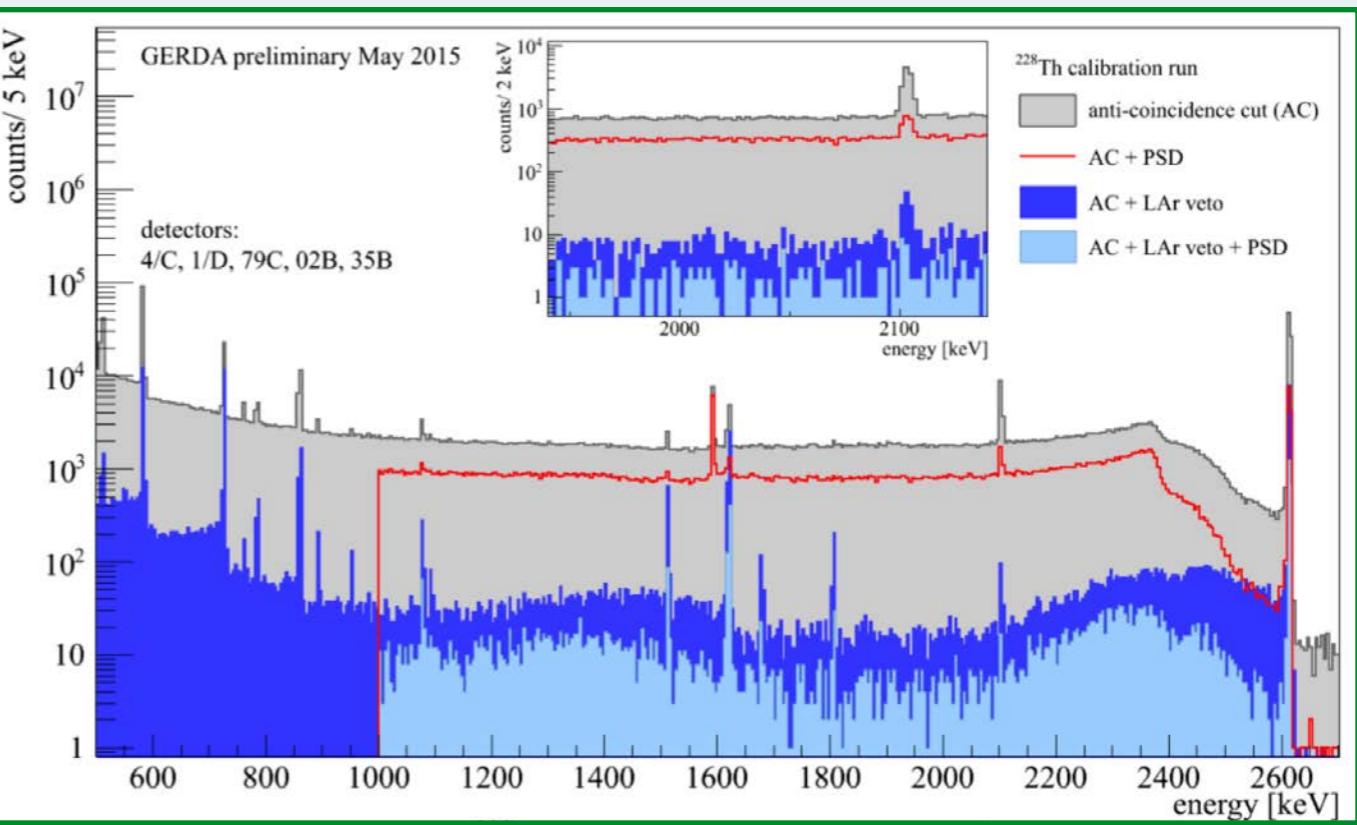
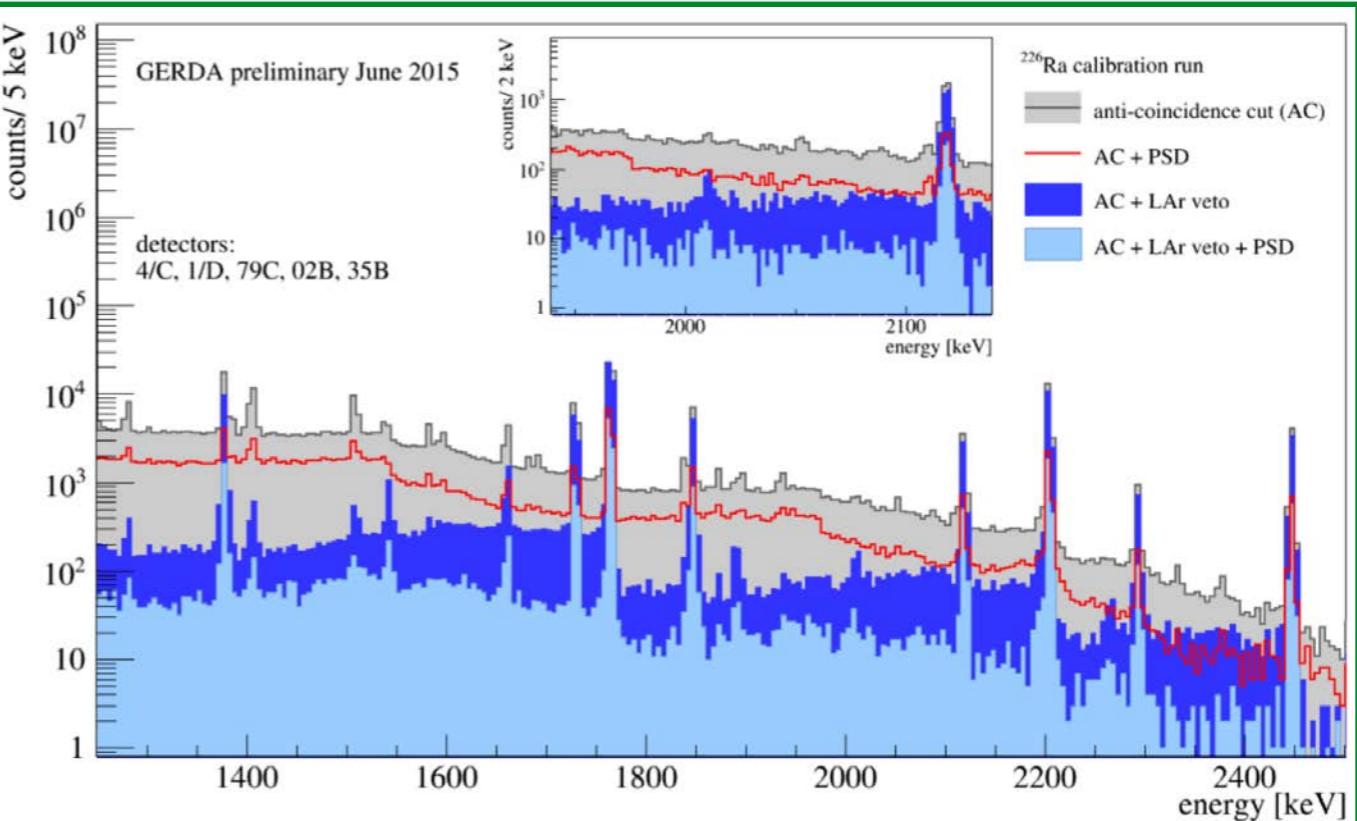
Liquid Argon scintillation as background veto

- PMT arrays on top and bottom
- Si-photomultipliers coupled to WLS fibers

Suppression factor (AC + LAr veto + BEGe PSD)

^{228}Th : 433.1 ± 30.7

^{226}Ra : 29.4 ± 2.5



Summary

- Phase I background
an order of magnitude lower than HdM and IGEX
- GERDA background model consistent with observation
- Background dominated by close sources
- Flat background at $Q_{\beta\beta}$
- Higher background than screening expectation
Possibly due to detectors surface contamination
- Further mitigation of background in Phase II