Status and results of the GERDA experiment.

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GERDA collaboration

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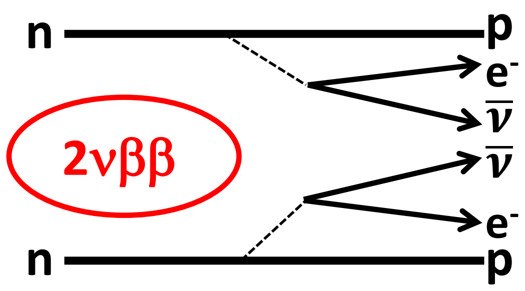
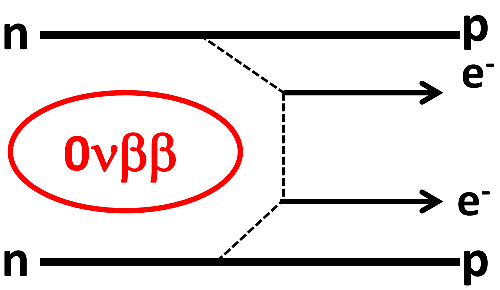
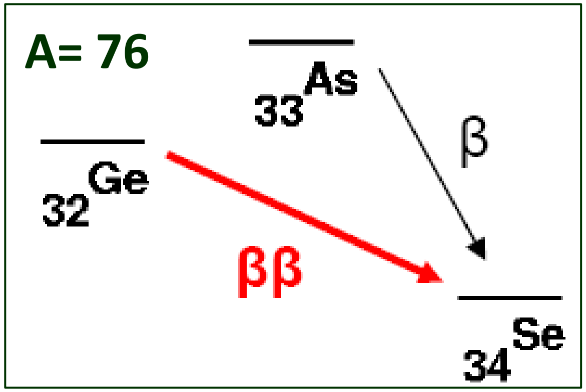
The **GER**manium **D**etector **A**rray
(GERDA) Collaboration:
~ 100 physicists
18 institutes
6 countries

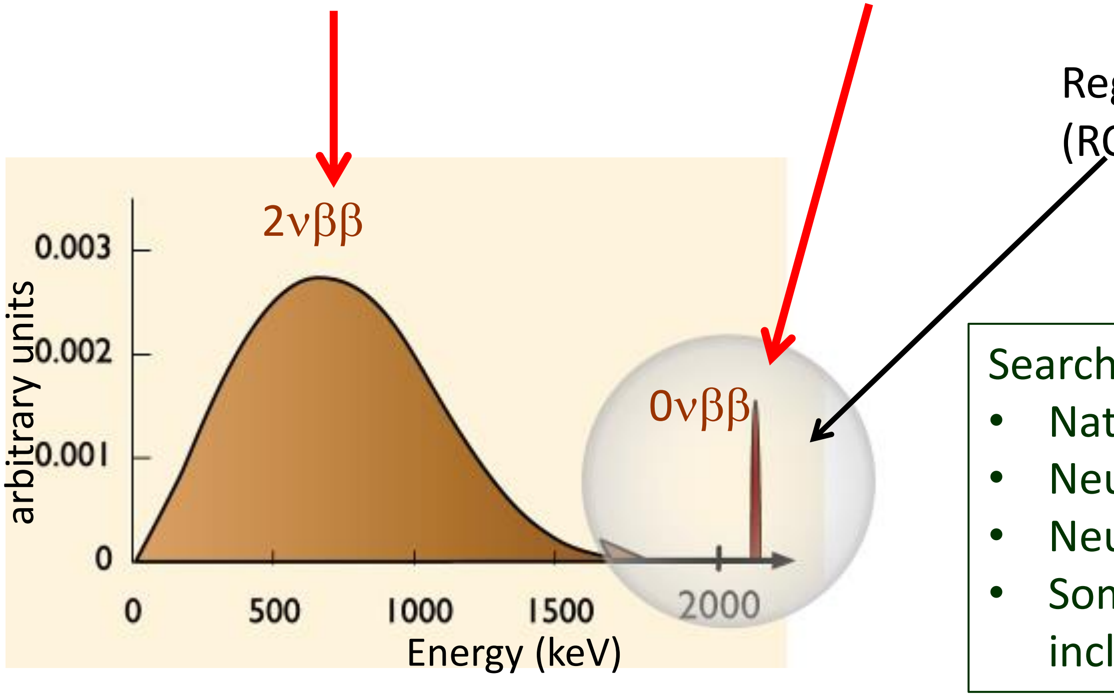
Motivation

Search for the neutrinoless double beta (0νββ) decay is a good way to search for the physics beyond the Standard Model. The observation of such a decay would prove that lepton number is not conserved.









Region of interest (ROI) of 0νββ

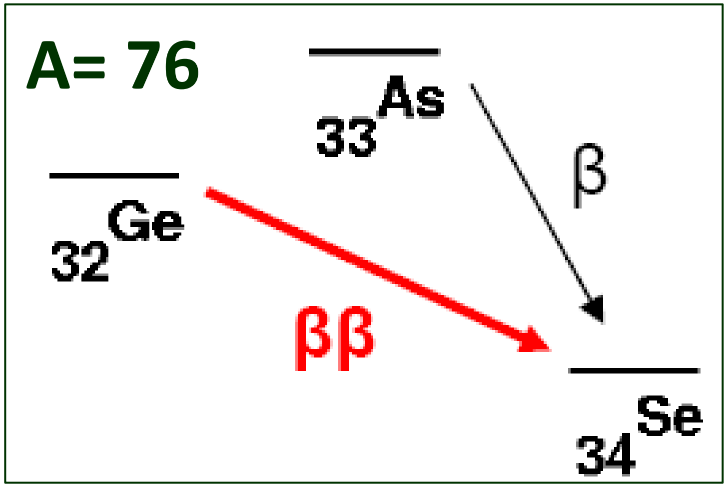
Searching for 0νββ helps to understand:
- Nature of ν (Dirac or Majorana)
- Neutrino mass scale
- Neutrino hierarchy
- Some fields in particle physics including cosmology

^{76}Ge 0νββ decay

The GERDA experiment is a low background experiment aimed to search for ^{76}Ge 0νββ decay.

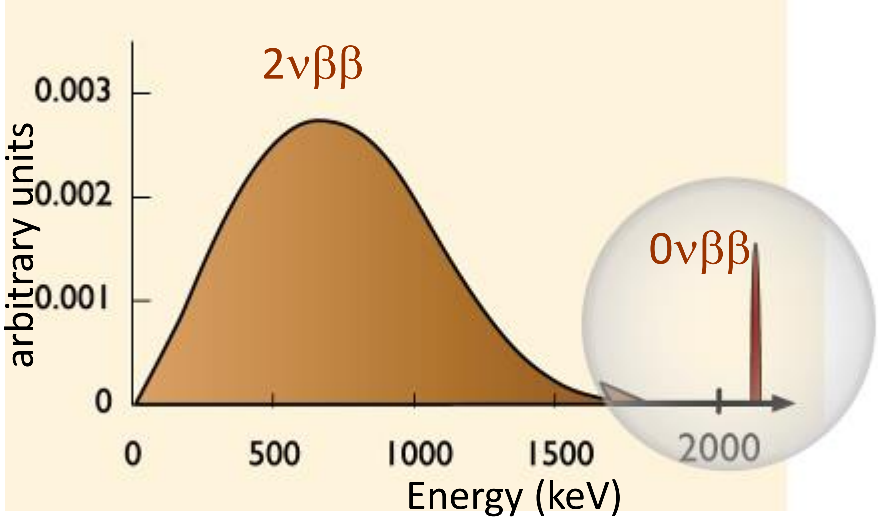
$$T^{0\nu}_{1/2} \propto \langle m_{\beta\beta}\rangle^{-2} \propto const \sqrt{\frac{M \times t}{\Delta E \times B}}$$

M	Mass
t	Time
B	Background rate
ΔE	Energy resolution



Search with enriched HPGe detectors enriched with ^{76}Ge:

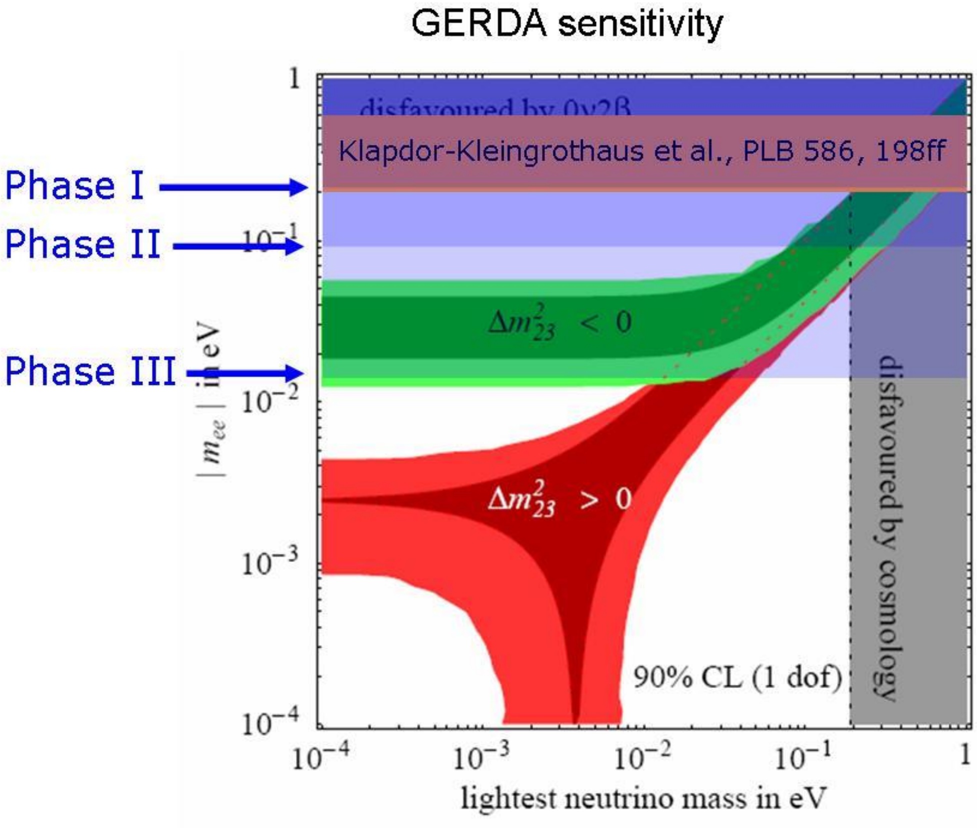
- Detector = source
- Very good detector’s energy resolution: better than 0.2%
- Intrinsically pure material



Motivation

Part of HdM Collaboration, claimed evidence for 0νββ decay observation with the best fit $T_{1/2} = 1.19 \cdot 10^{25}$ yr [1].

[1] H.V. Klapdor-Kleingrothaus, et.al, NIM A 522 (2004)



The aim of GERDA is to test the claim of discovery by part of Heidelberg-Moscow Collaboration, and, in a second phase, to achieve much better sensitivity than recent experiments.

Phase I: Deployed 8 existing enriched detectors (18 kg total), 3 natural HPGe detectors (in total 7.6 kg of natural Ge) and 5 enriched BEGe (3.6 kg from 7/07/2012)

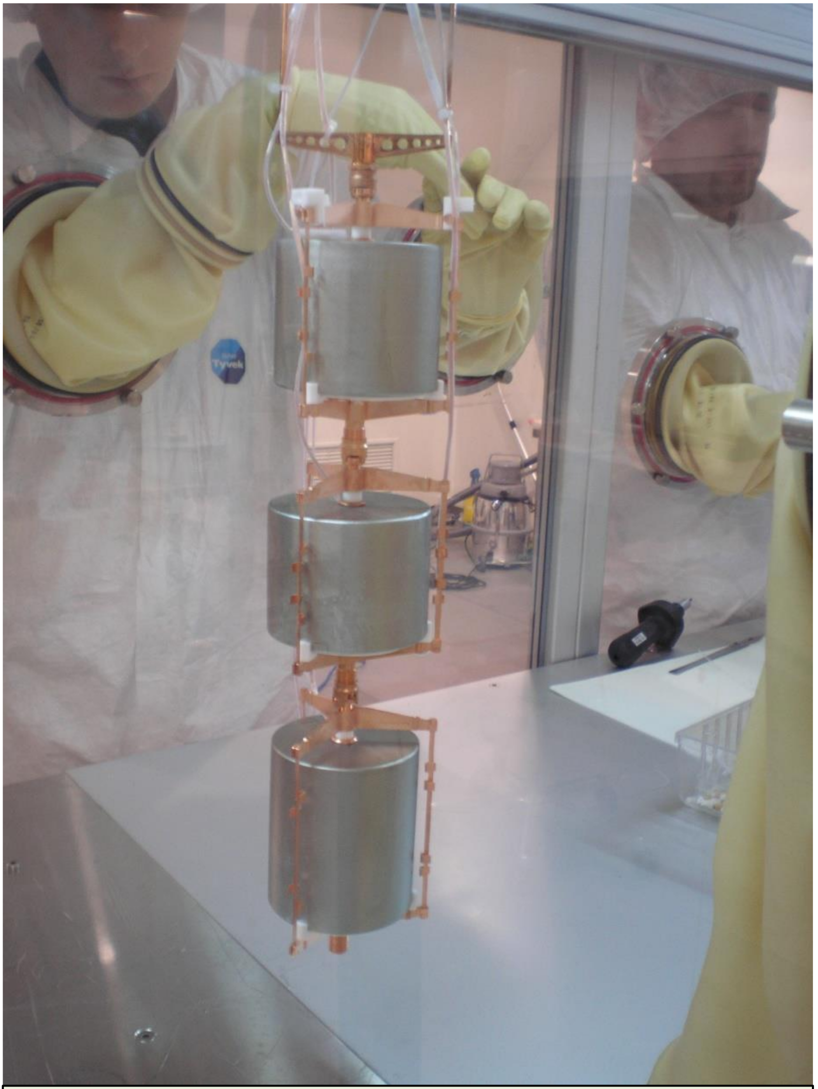
Phase II: In addition new enriched BEGe detectors with total mass of about 20 kg will be incorporated together with liquid argon (LAr) scintillation veto.

Phase III: Depending on the results of Phase II possible GERDA-MAJORANA collaboration aimed to cover inverted hierarchy. Planned BI ~ 0.1 counts (keV · t · year).

General concept

In IGEX and HdM experiments it was shown that main part of the detector's background is due to radioactive contamination of surrounding materials (including copper cryostat).

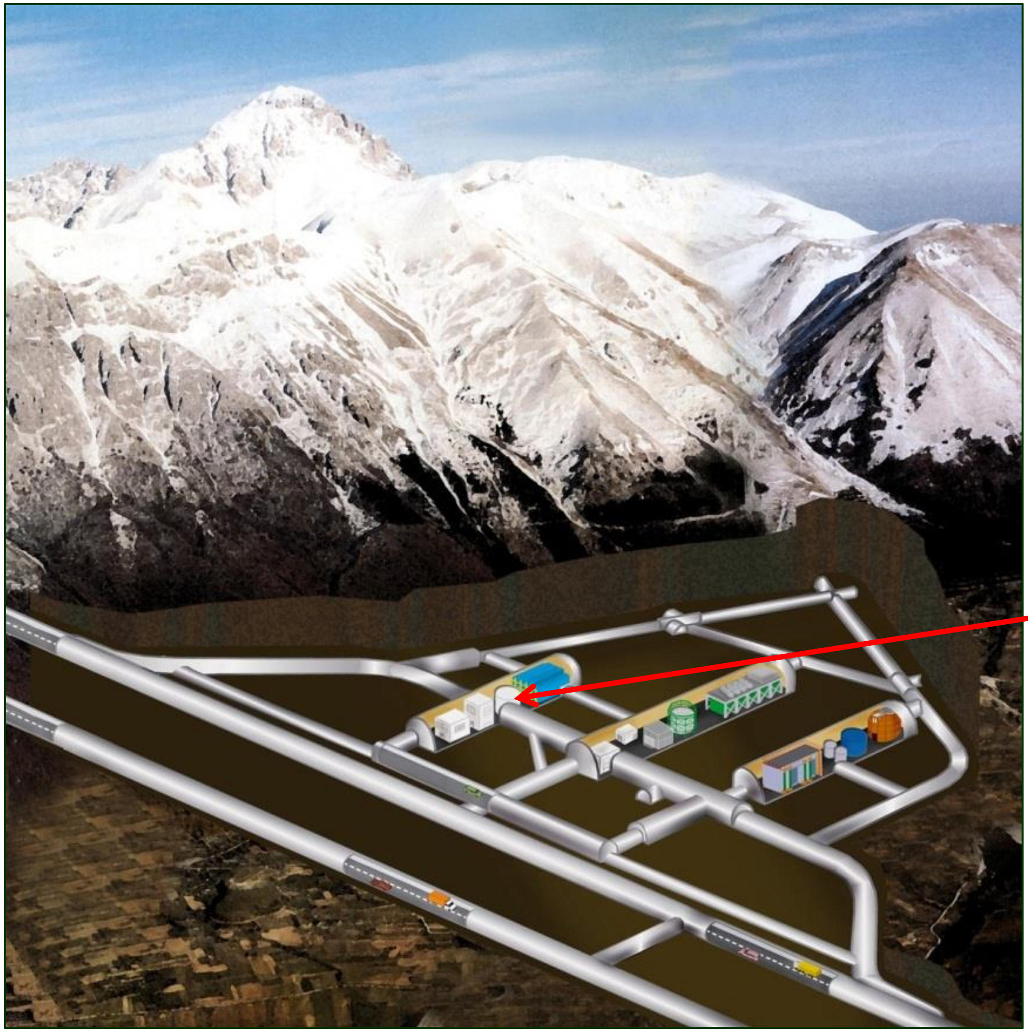
So, in GERDA we use "naked" Ge detectors submerged into the High-Purity liquid Ar which shields from the radiation and cools down the Ge detectors.



~80 g Cu, ~10 g PTFE, ~1 g Si per detector

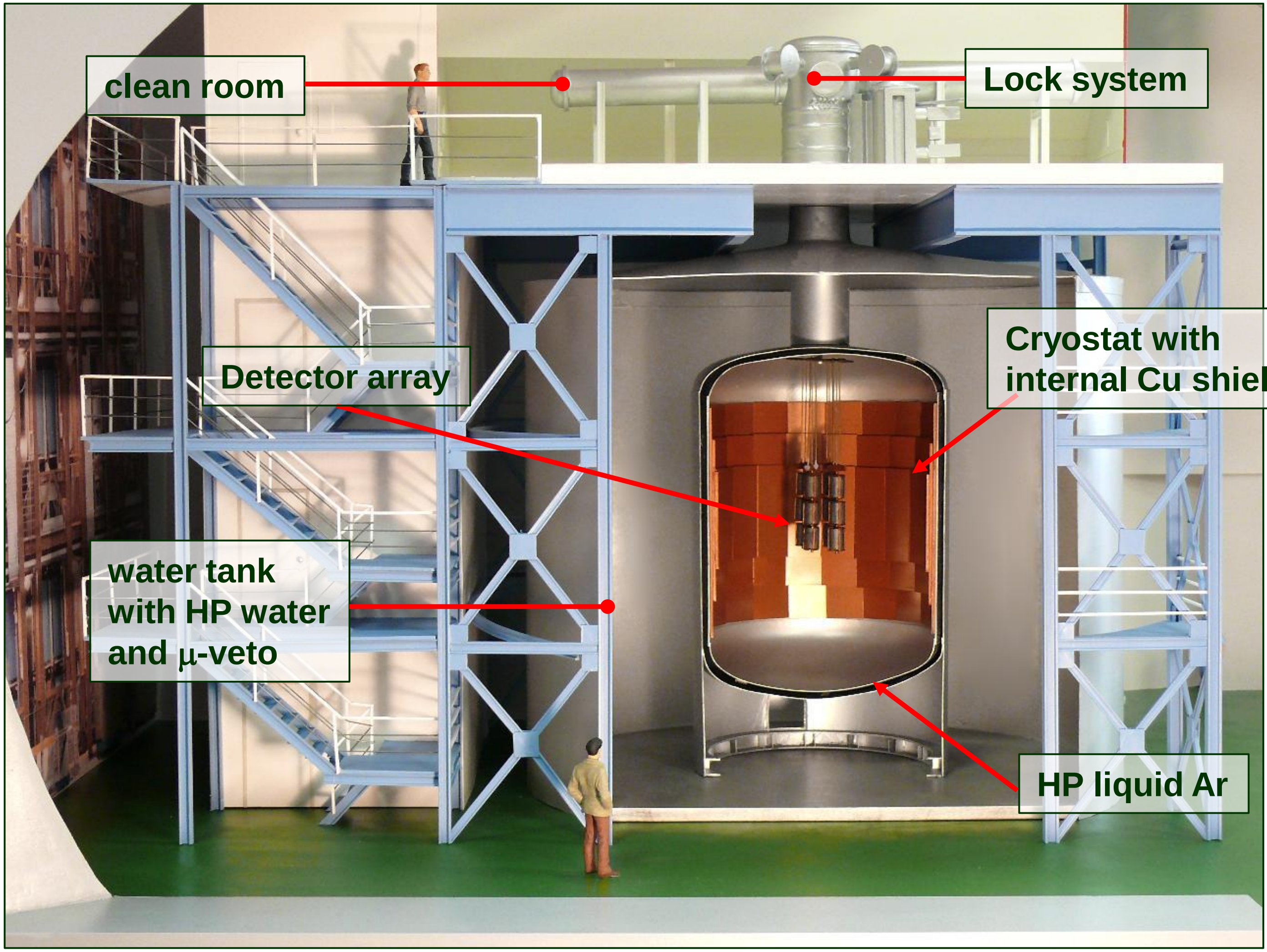
Background reduction

GERDA experiment located at LNGS underground laboratory of INFN (Italy). The rock overburden is equivalent to 3500 m.w.e. This allows to reduce μ (~ 10^6 times) and neutron flux induced by cosmic radiation.



Scheme of GERDA experiment

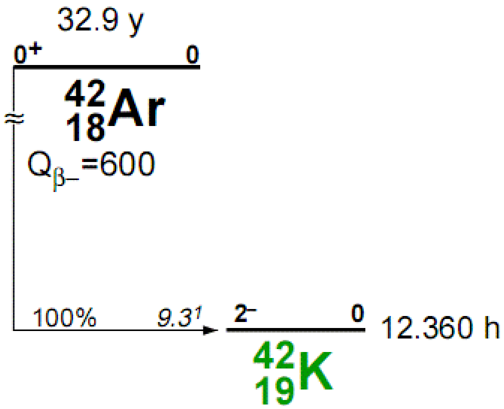
Bare germanium detectors enriched by ^{76}Ge, submerged into the high-purity liquid argon, are used in GERDA experiment. This allows to decrease background from the surrounding materials, liquid argon shields from the radiation and cools down the Ge detectors.

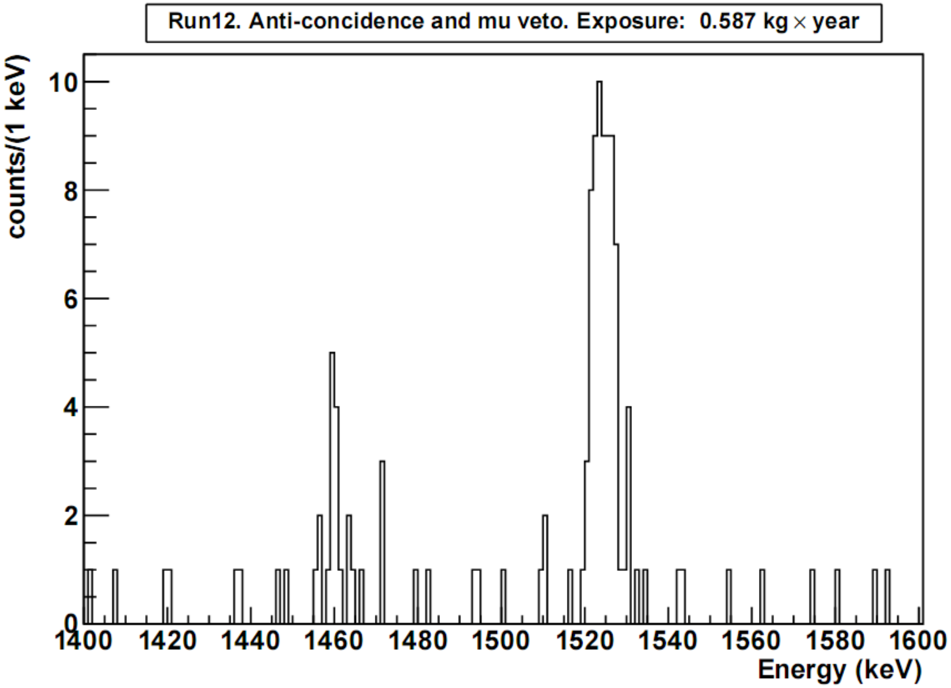


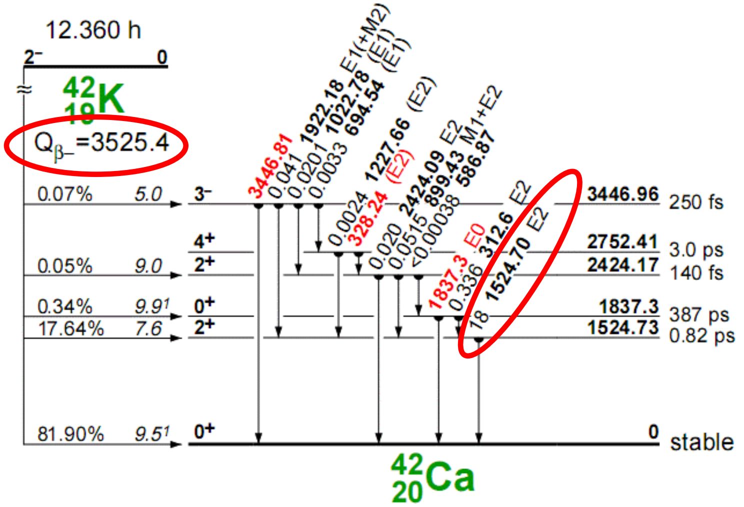
Unexpected ^{42}Ar background

In the **proposal of GERDA** for estimation of the ^{42}Ar activity in liquid Ar in GERDA cryostat, the limit < 30 μBq/kg [Barabash et al., 2002] has been taken into account.

Already during first commissioning runs with non-enriched detectors it was found that peak of 1525 keV peak from ^{42}K (daughter of ^{42}Ar) has at least 10 times higher intensity than expected from the activity of ^{42}Ar (limit obtained in [Bar02]). It will be shown later that we are able to decrease it by preventing of collection of ^{42}K ions by electric field of the detector.

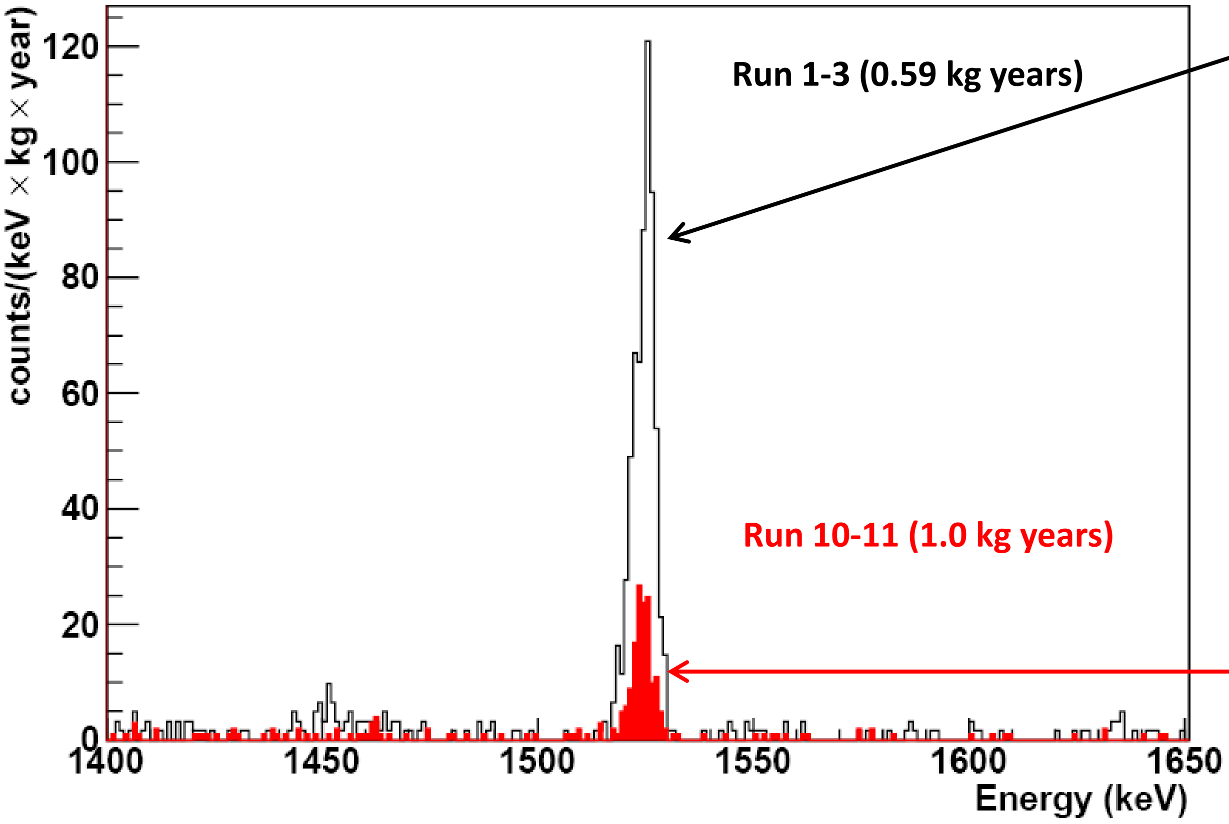


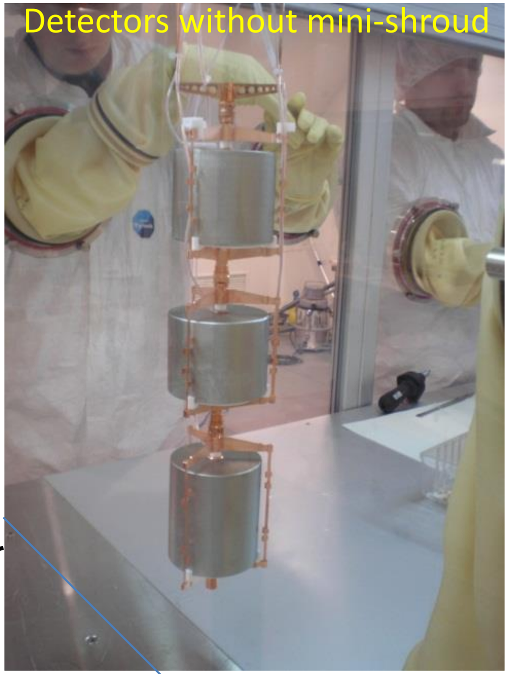




Mini-shroud

By surrounding the detectors with a copper foil (so called mini-shroud) it is possible to screen E-field around the detector and decrease collection of ^{42}K ions toward the surface of the detector. Intensity of ^{42}K peak in GERDA is significantly higher than with “E-field free” configuration. ^{42}K background contribution from analysis of the GERDA Phase I data estimated to be about **3 x 10^{-3} cts/(keV·kg·yr)** near ROI of 0νββ.

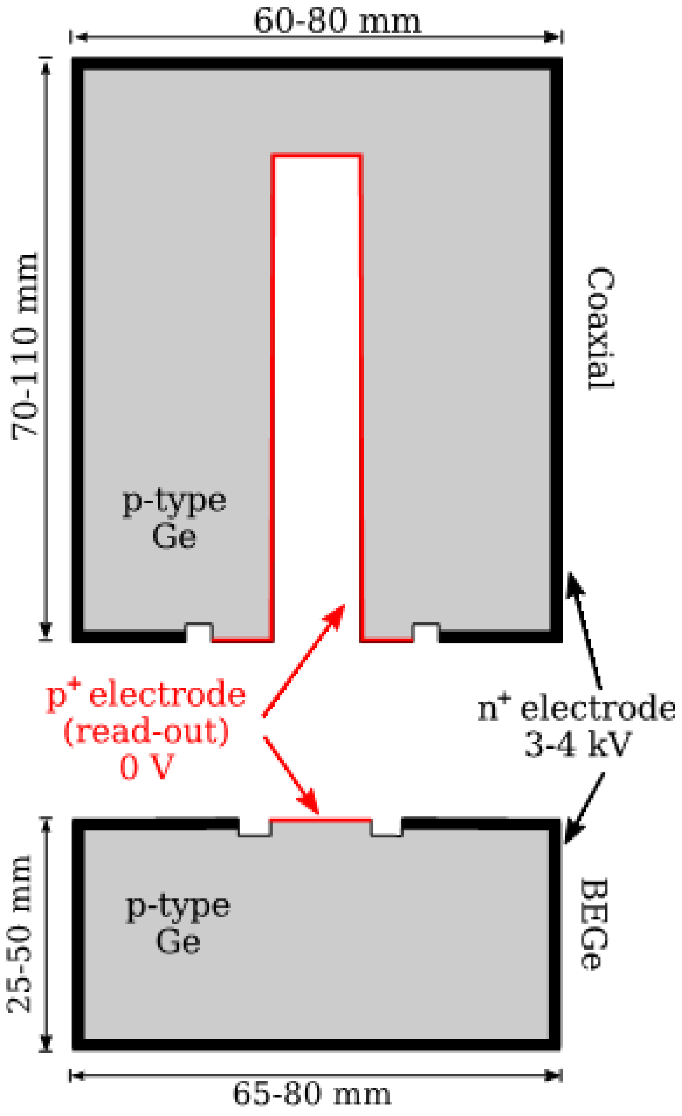


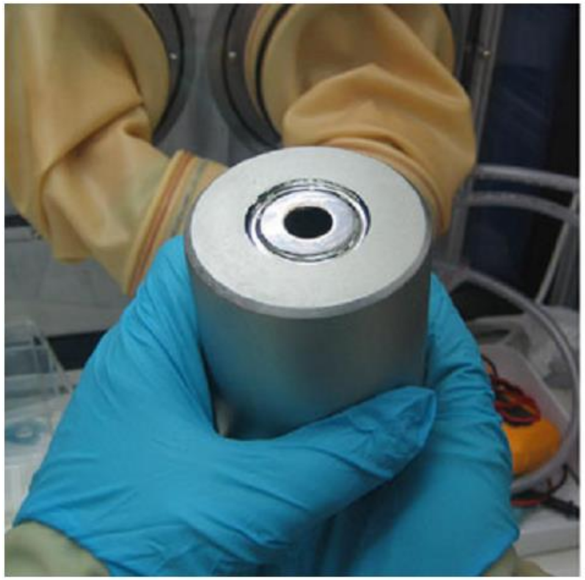

Detectors without mini-shroud

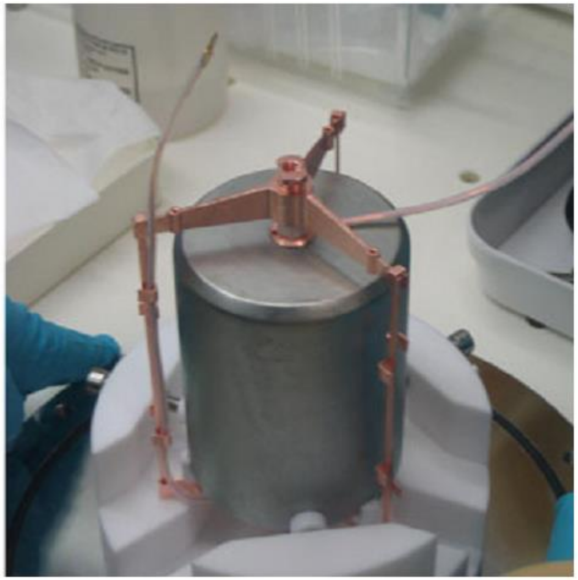

Detectors with mini-shroud made from copper foil

Phase I data taking

Phase I data taking with the enriched detectors started on November 9, 2011. For Phase I all eight HPGe coaxial detectors from the former HdM and IGEX experiments were refurbished and redeployed.
Also 3 natural HPGe coaxial detectors (in total 7.6 kg of natural Ge) and 5 enriched new BEGe detectors (3.6 kg from 7/07/2012) used for Phase I data taking.



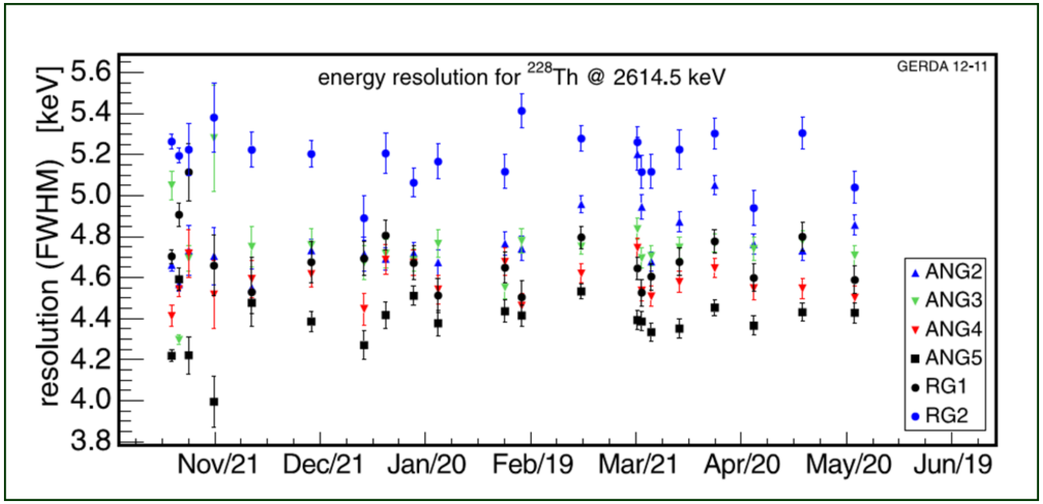




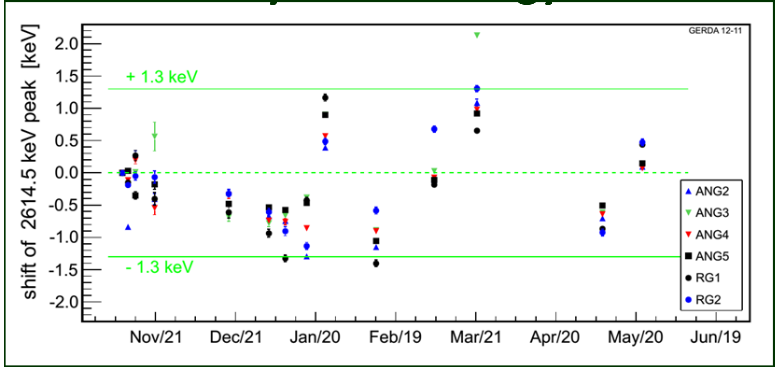
HPGe detectors in GERDA

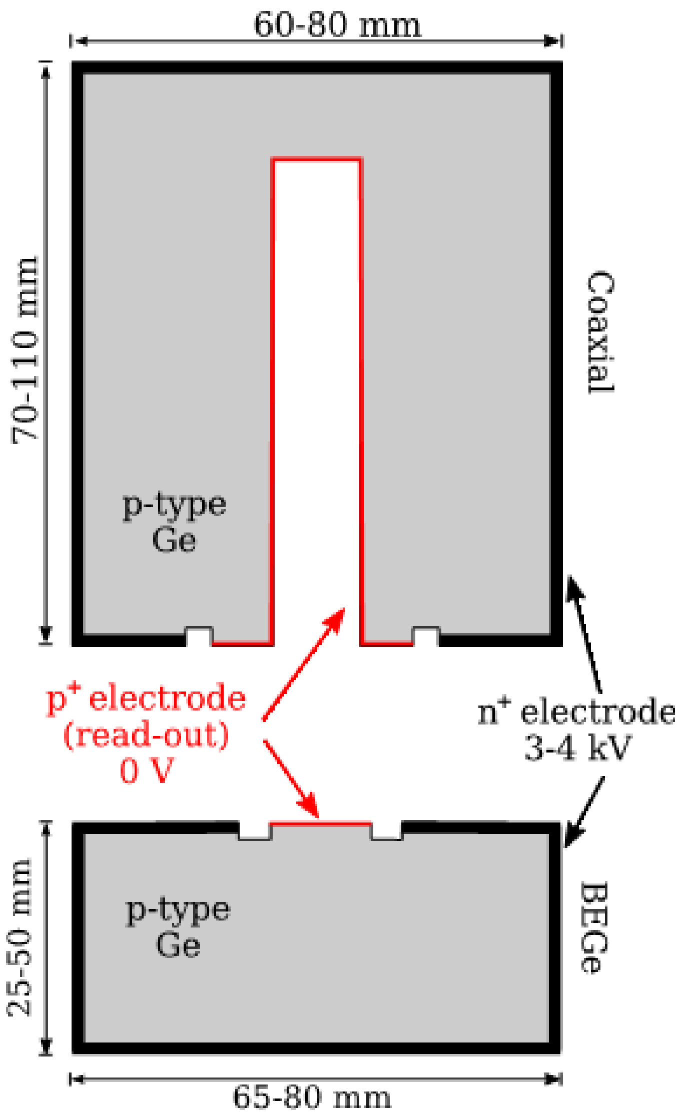
Most of the detectors show stable performance and good energy resolution. Average resolution of coaxial type detectors at $Q_{\beta\beta}$ is 4.8 keV. Average resolution of the BEGe is 3.2 keV (FWHM).

Resolution of the detectors at 2.6 MeV



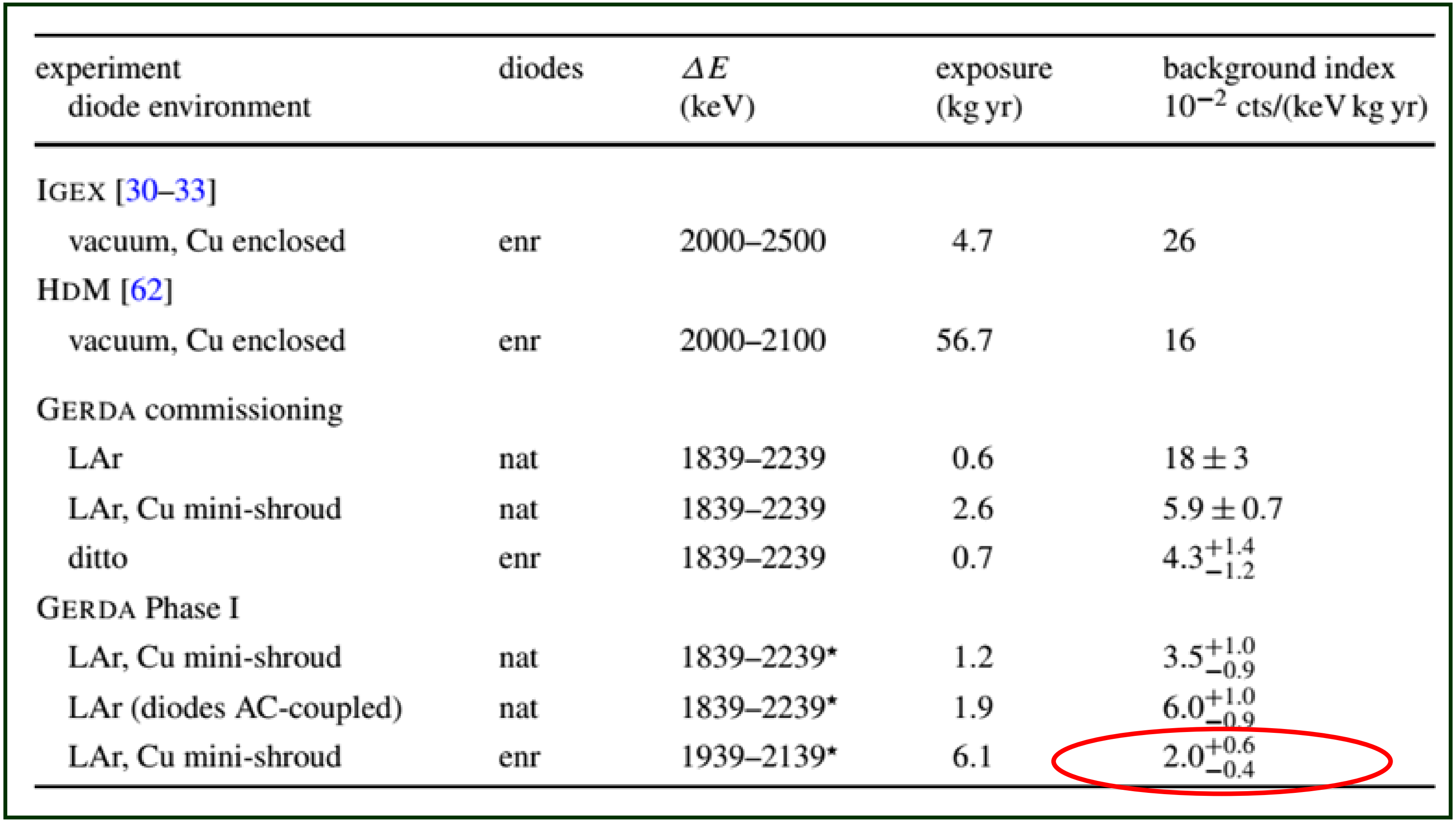
Stability of the energy scale





Comparison of the BI

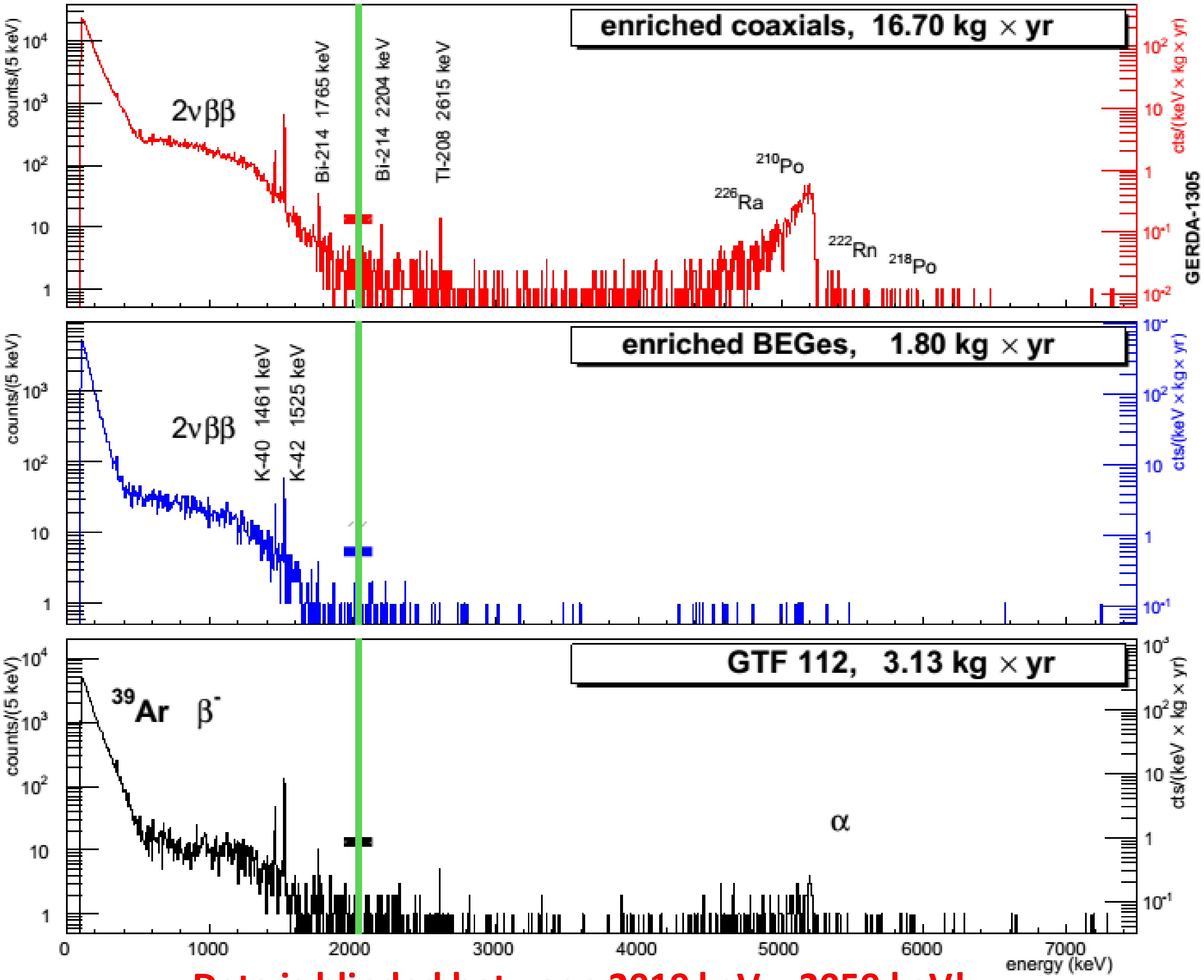
Background index (BI) in ROI during the commissioning and the first part of Phase I. Corresponding values are shown also for the IGEX and HdM experiments [2].



experiment diode environment	diodes	ΔE (keV)	exposure (kg yr)	background index 10^{-2} cts/(keV kg yr)
IGEX [30–33]				
vacuum, Cu enclosed	enr	2000–2500	4.7	26
HdM [62]				
vacuum, Cu enclosed	enr	2000–2100	56.7	16
GERDA commissioning				
LAr	nat	1839–2239	0.6	18 ± 3
LAr, Cu mini-shroud	nat	1839–2239	2.6	5.9 ± 0.7
ditto	enr	1839–2239	0.7	$4.3^{+1.4}_{-1.2}$
GERDA Phase I				
LAr, Cu mini-shroud	nat	1839–2239*	1.2	$3.5^{+1.0}_{-0.9}$
LAr (diodes AC-coupled)	nat	1839–2239*	1.9	$6.0^{+1.0}_{-0.9}$
LAr, Cu mini-shroud	enr	1939–2139*	6.1	$2.0^{+0.6}_{-0.4}$

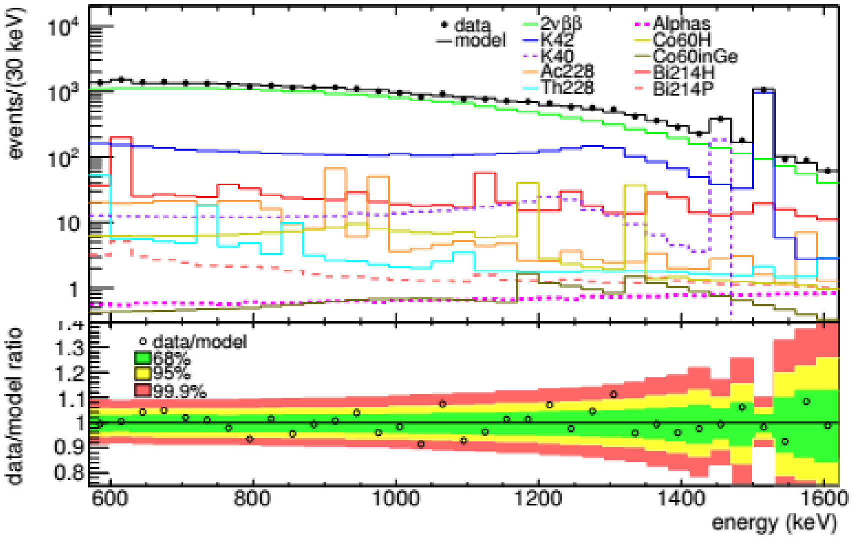
[2] H.-K.Ackermann et al., Eur. Phys. J. C 73 (2013) 2330.

Energy spectrum



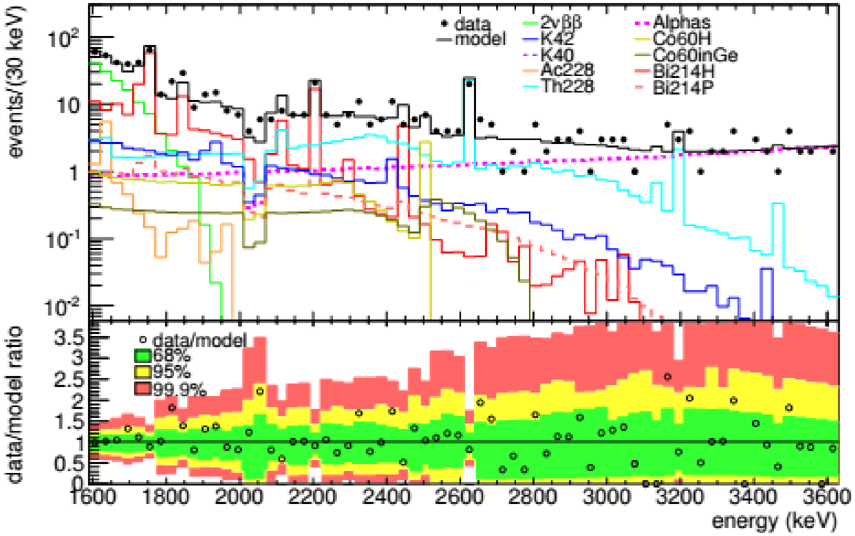
Data is blinded between 2019 keV – 2059 keV!

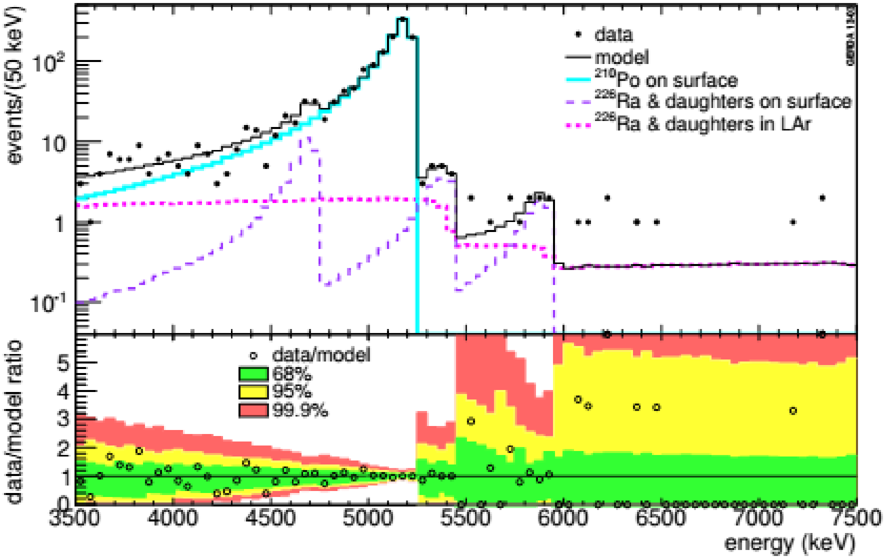
Background model



Background model explain spectrum very well. No peaks and flat background in ROI is expected. See more [3].

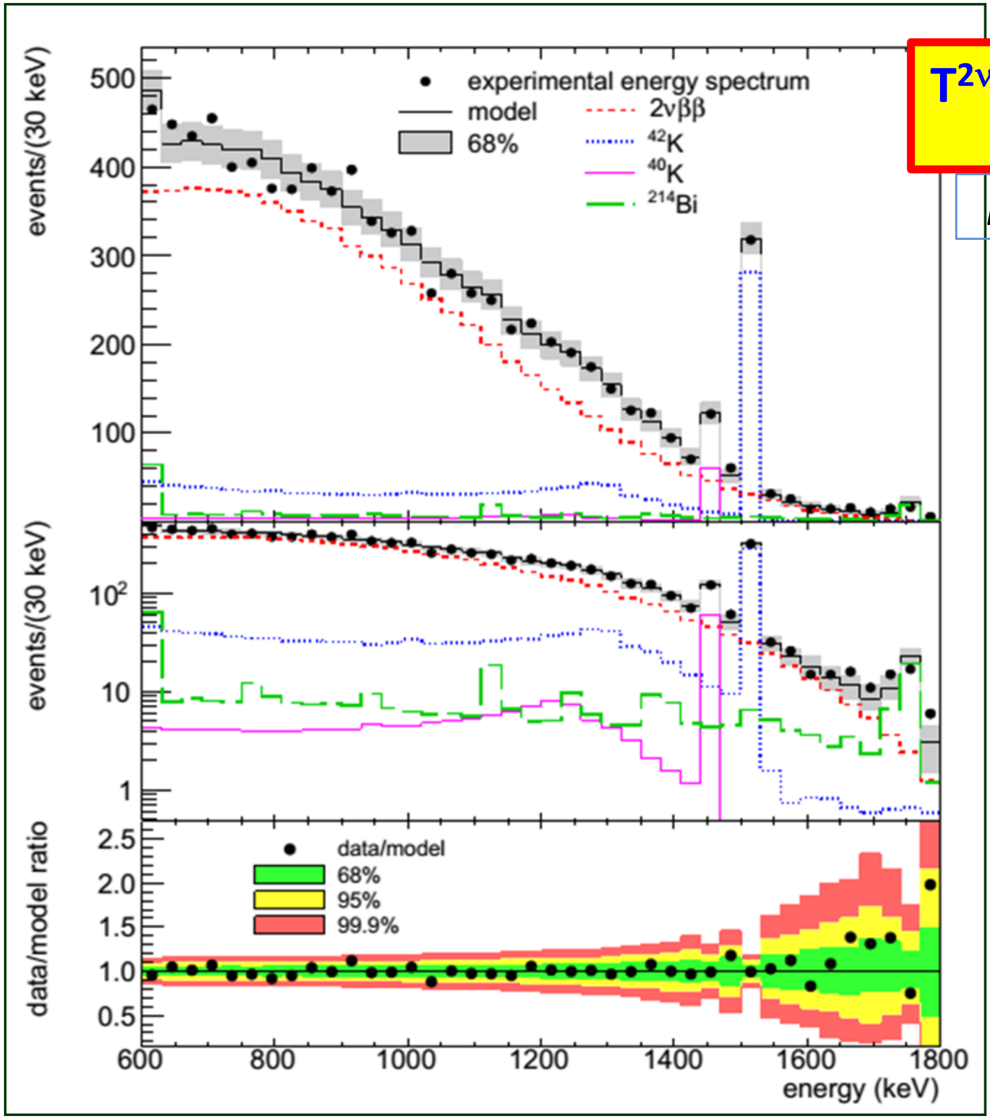
[3] http://arxiv.org/abs/1306.5084





Measurements of $T^{2\nu}_{1/2}$

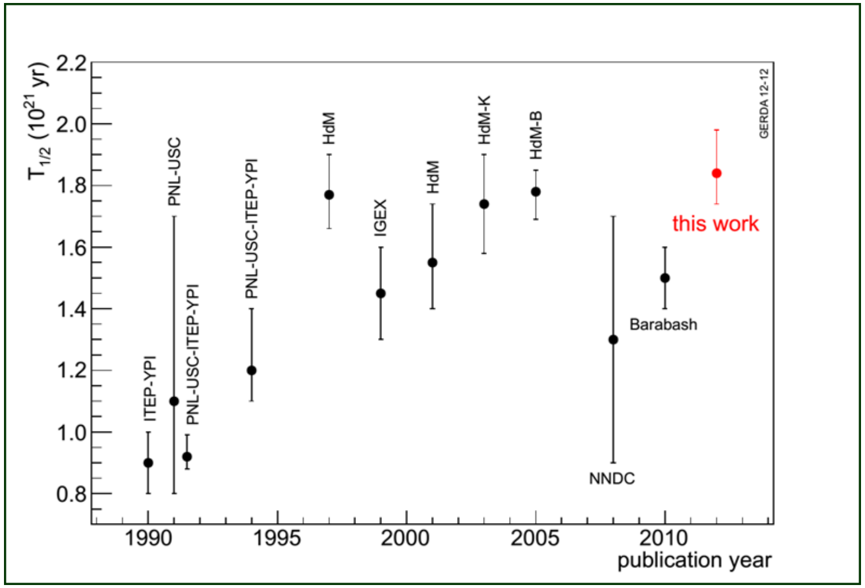
From analysis of first 126 days of data taking obtained half-life of the $2\nu\beta\beta$ decay [4]:



$T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08\,\mathrm{fit}}\;{}^{+0.11}_{-0.06\,\mathrm{syst}}) \cdot 10^{21}$ yr

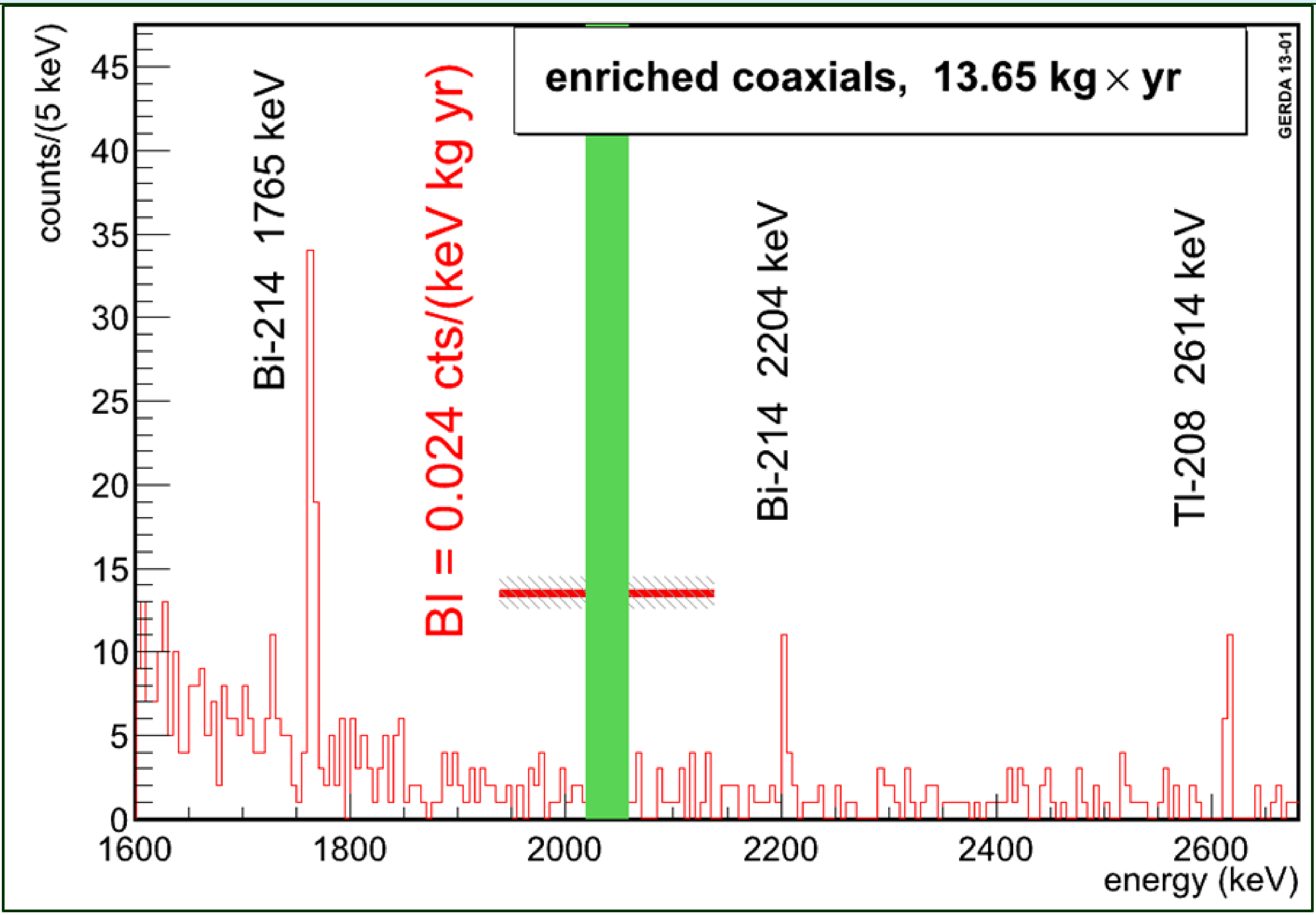
[4] *J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110.*

Comparison with the previous measurements

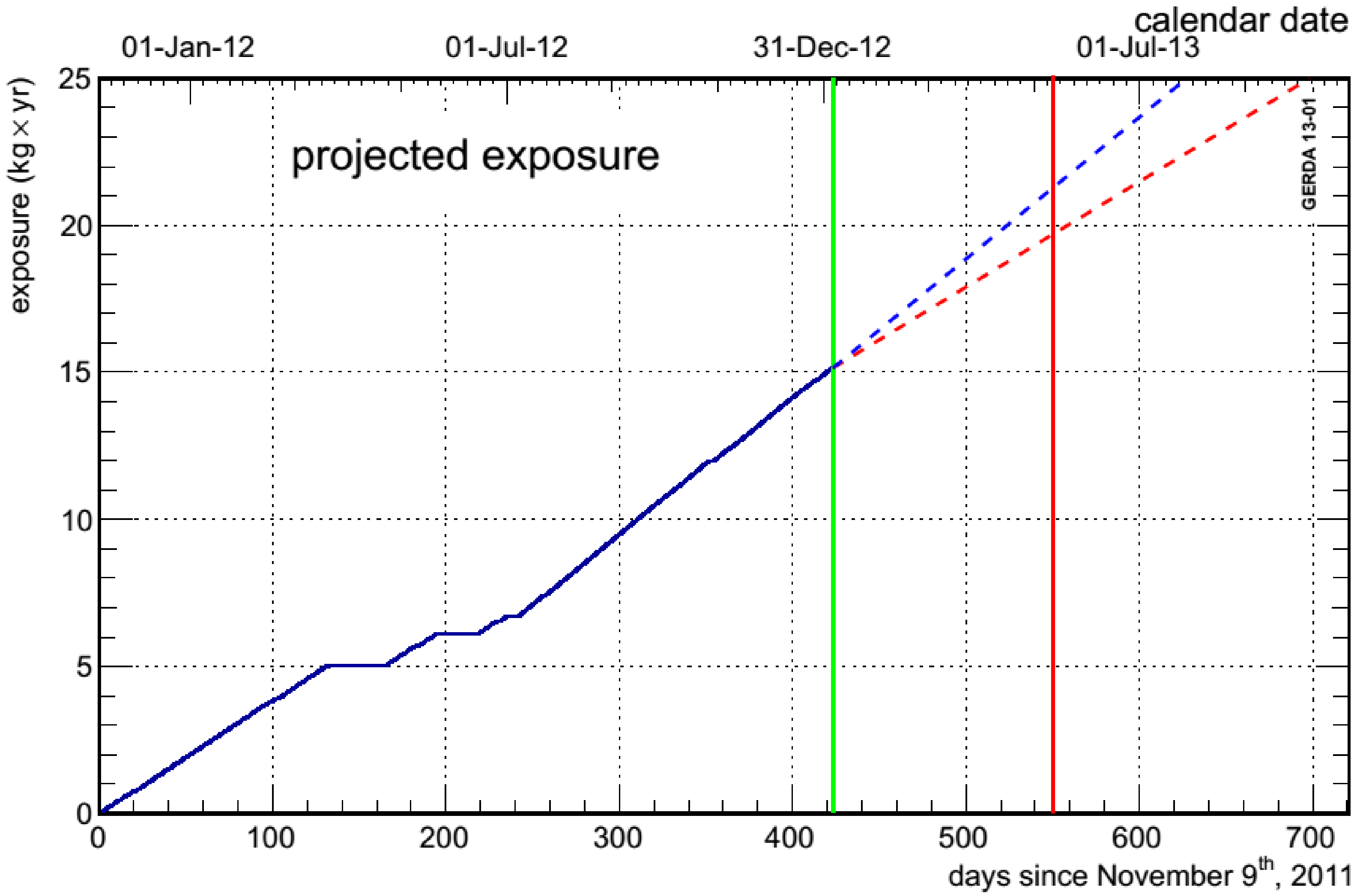


ROI of $0\nu\beta\beta$

BI for coaxial detectors in $Q_{\beta\beta}$± 100 keV: **0.024 cts/(keV·kg·yr)**. Excluding higher background short period in July 2012: **0.0185 cts/(keV·kg·yr)**. This is about 8 times better than BI in HdM experiment. By applying of pulse shape discrimination (PSD) background index below 10^{-2} cts/(keV·kg·yr) can be obtained.



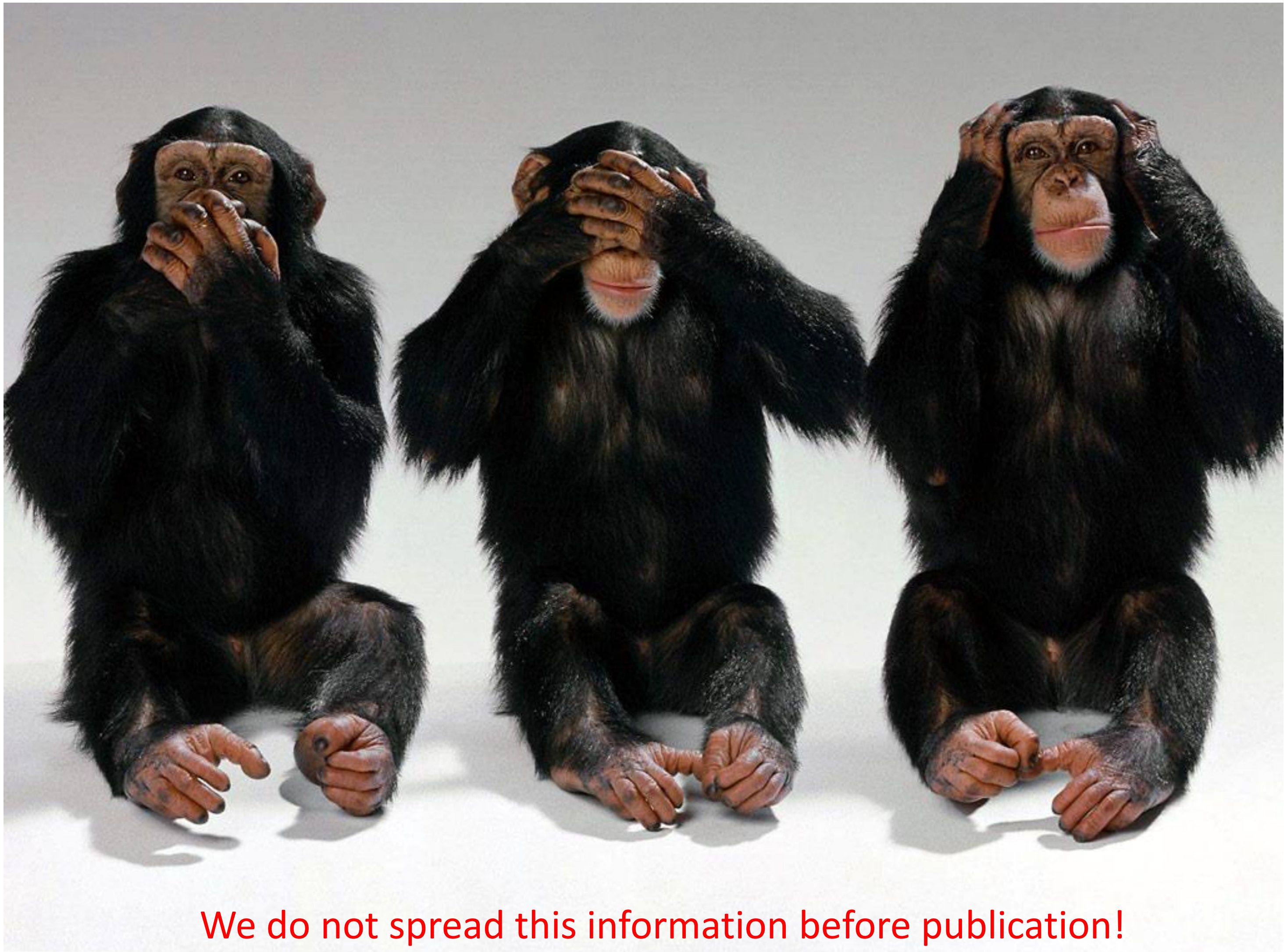
Integrated exposure



Goal of Phase I data taking of 20 kg·yr is currently accomplished.

Measurements of 0νββ

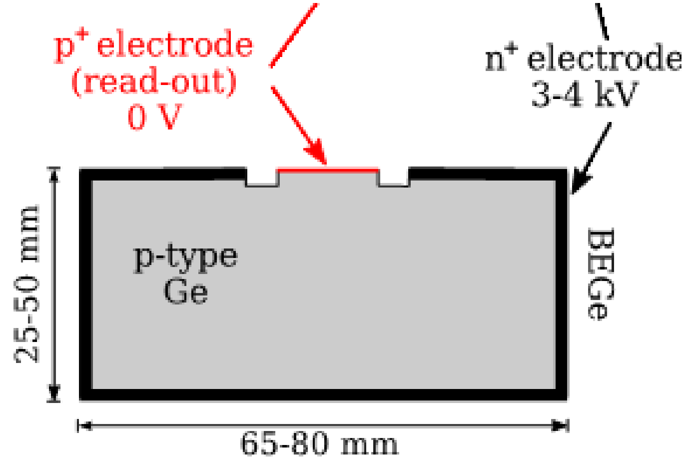
In June 2013 we fix analysis procedure including PSD and open blinded window of ROI of 0νββ. Results will be published in the coming days and you will get know what is inside.



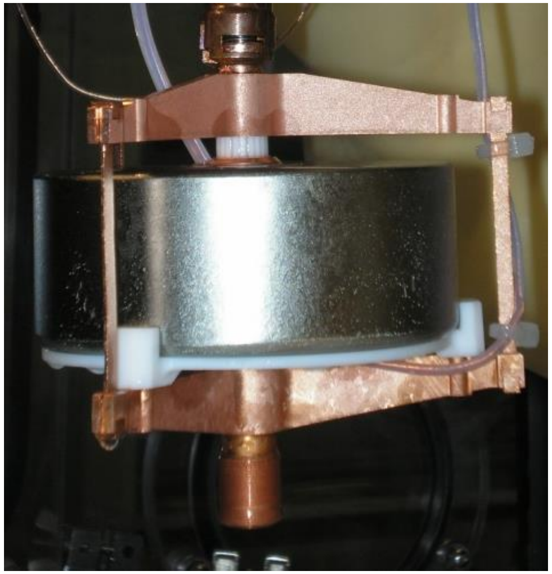
We do not spread this information before publication!

Phase II preparations

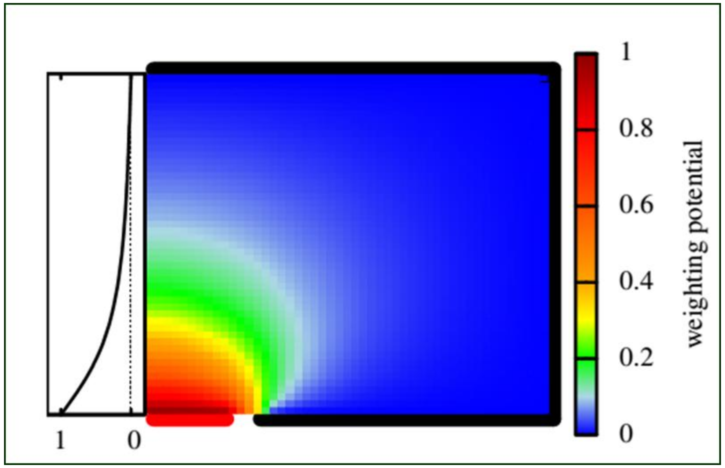
Data taking for Phase I is finished and Phase II installations will be started in July 2013. In Phase II **20 kg of new enriched BEGe** detectors will be added together with liquid argon (LAr) scintillation veto.



Currently about 20 kg == 30 diodes of enriched BEGe detectors has been produced and tested in vacuum cryostat. 5 enriched BEGe were successfully tested in GERDA and they show good performance. Detectors have impressive resolution (up to 1.6 keV @ 1.3 MeV in a vacuum cryostat) and powerful pulse shape discrimination (PSD) capability.

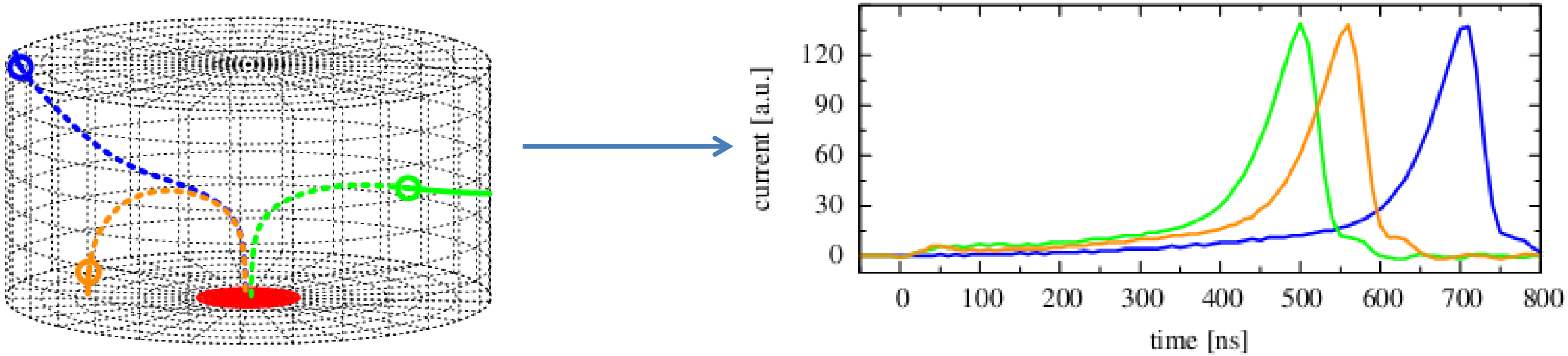


Simulation of the e-field in BEGe [5]

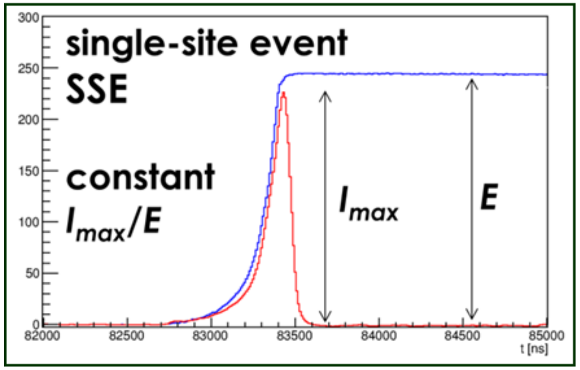


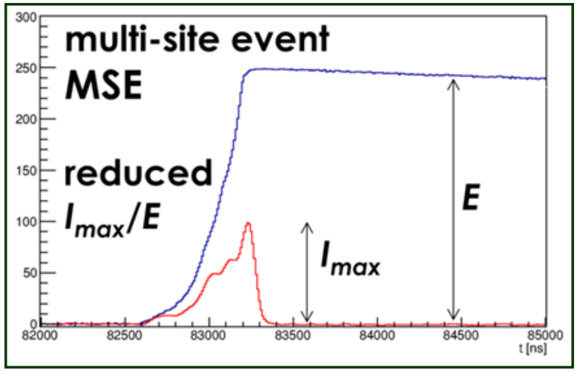
[5] *JINST 4 (2009) P10007.*

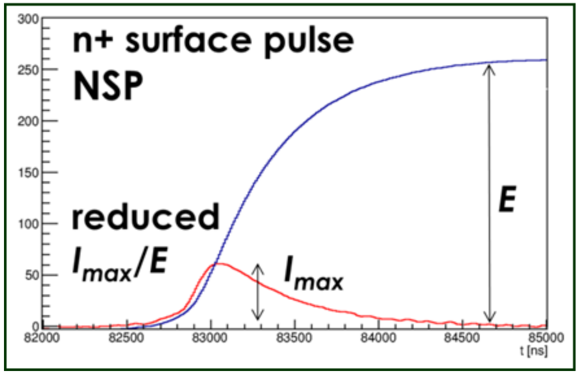
PSD of BEGe

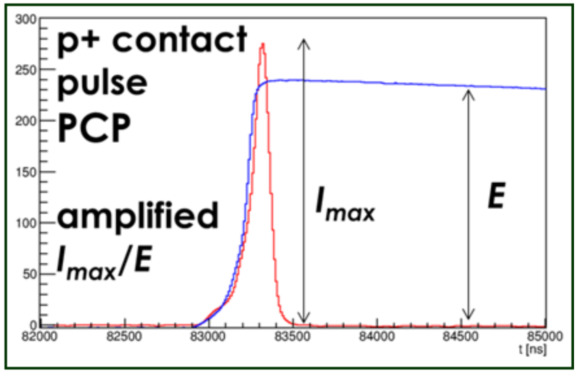


Good PSD based on the “funnelling” effect: similar shape of the pulses coming from different places of the detector allows to have powerful PSD.



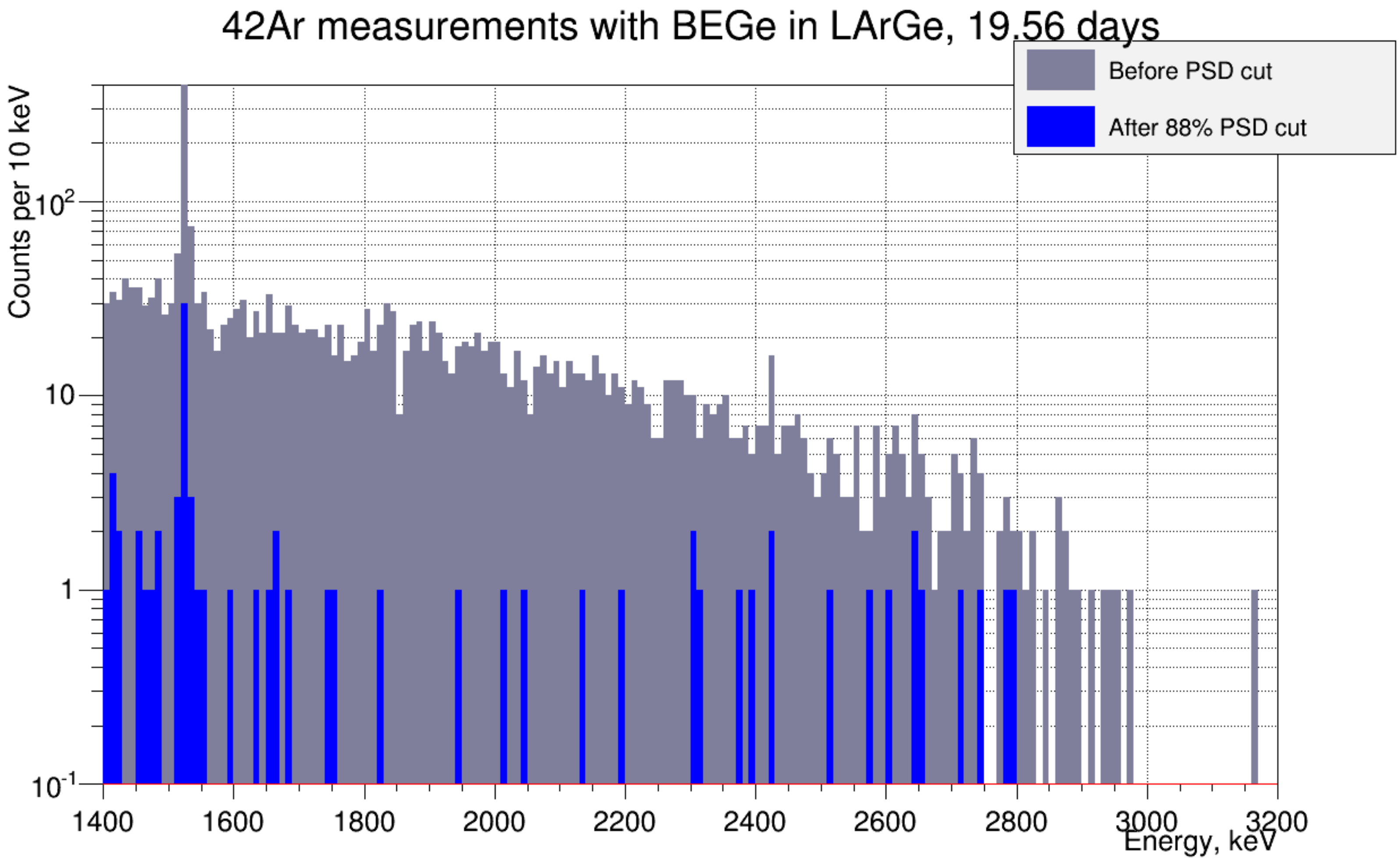






PSD of BEGe

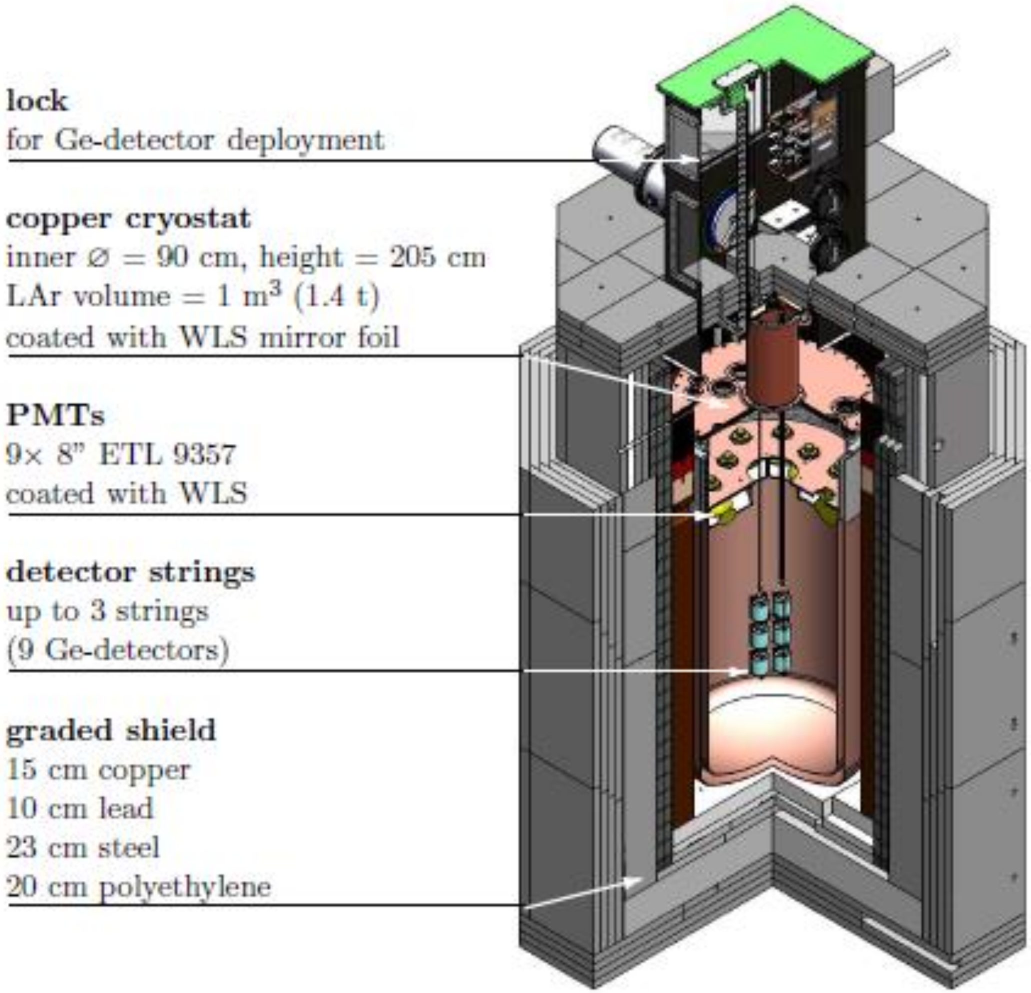
PSD method allows efficiently suppress background coming from ^{42}K. Such type of the events usually deposit energy near n+ contact -> different shape (“slow pulses”).



Number events from ^{42}K in 400 keV near 0νββ which survive PSD cut are < **1%** [90% C.L.].

LArGe test facility

LArGe low background test facility has been created in order to study the possibility to suppress background by using anticoincidence with liquid Ar scintillation signal detected by PMTs. It was shown that liquid scintillation veto can efficiently suppress the background.



lock
for Ge-detector deployment

copper cryostat
inner ∅ = 90 cm, height = 205 cm
LAr volume = 1 m^3 (1.4 t)
coated with WLS mirror foil

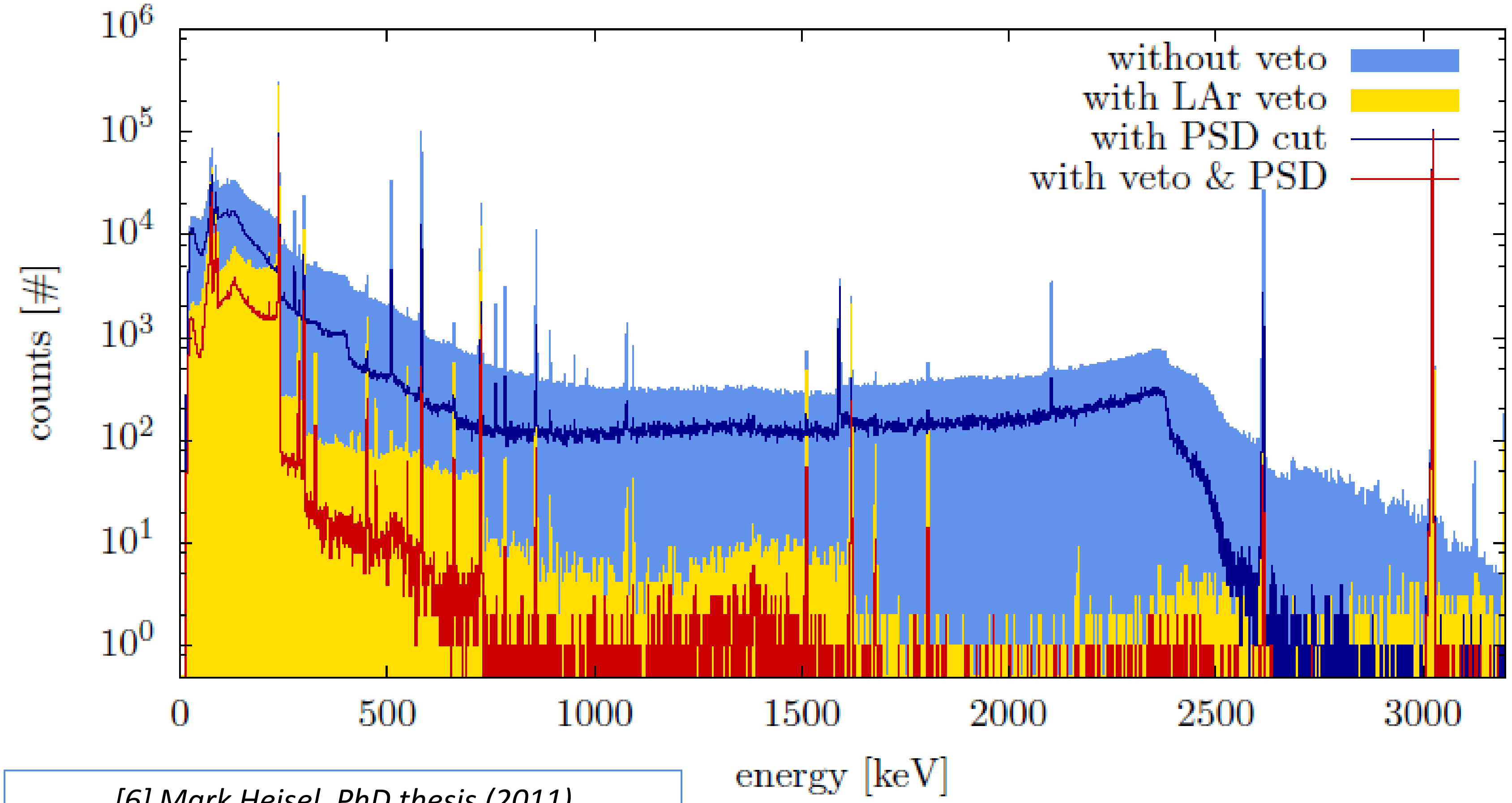
PMTs
9× 8" ETL 9357
coated with WLS

detector strings
up to 3 strings
(9 Ge-detectors)

graded shield
15 cm copper
10 cm lead
23 cm steel
20 cm polyethylene

Light instrumentation

Measurements with BEGe detector inside LArGe test facility show very good suppression of background. For ^{228}Th inner source the suppression factor > 5000 has been obtained after applying LAr VETO and PSD (but for other sources it can be lower for example for external ^{226}Ra it is only factor 18) [6]. That is why to reach goal of Phase II background index of < 10^{-3} cts/(keV·kg·yr) light scintillation veto will be implemented in GERDA experiment.



[6] Mark Heisel, PhD thesis (2011)

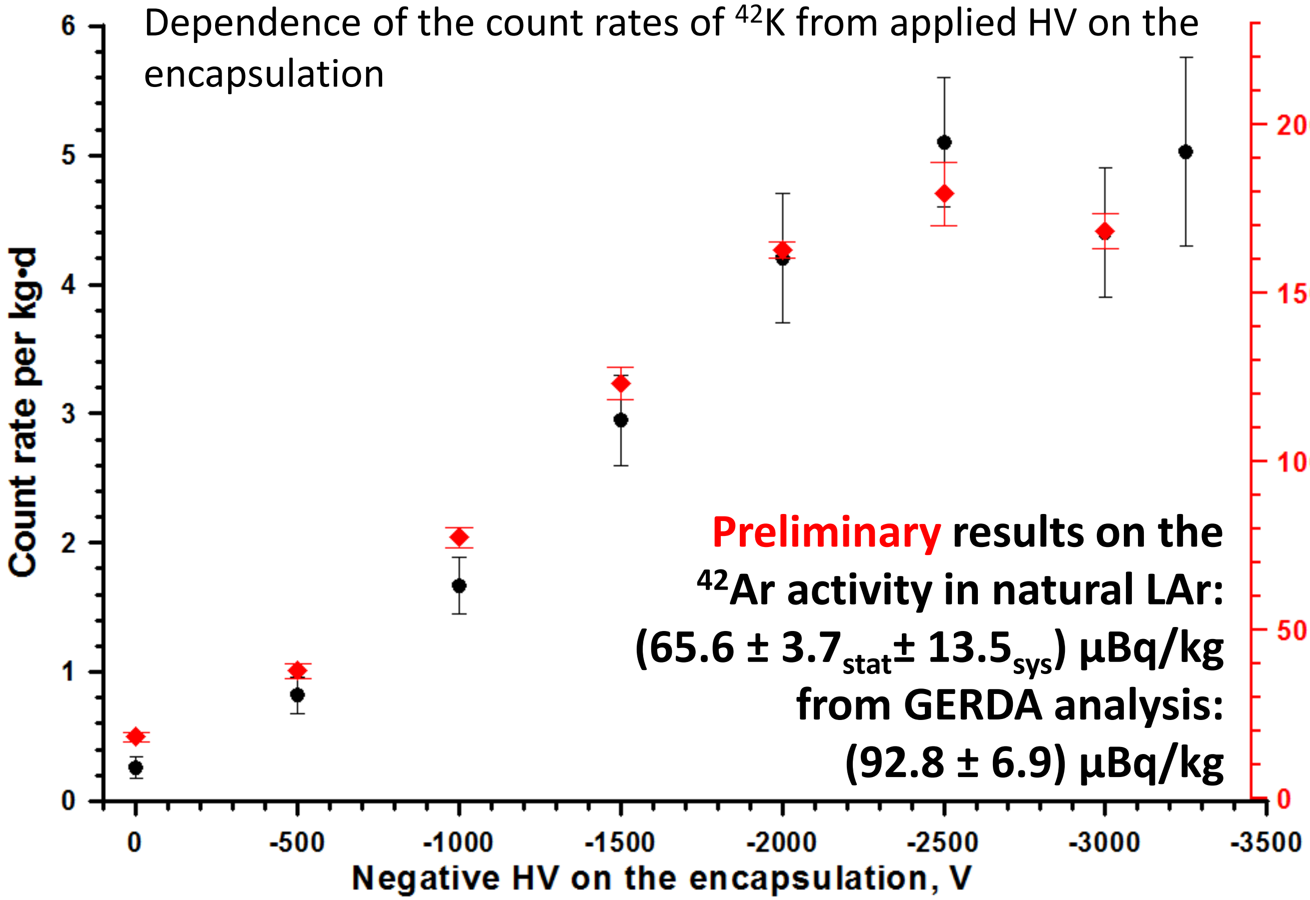
Conclusion

- GERDA experimental setup was successfully installed and shows good performance. Phase I data taking was started in November 2011 and stopped in May 21 2013.
- Average background index for enriched coaxial detectors was 0.02 cts/(keV·kg·yr). This about factor 8 better than in predecessor experiments with HPGe detectors.
- From analysis of first 126 days of data taking obtained half-life of the $2\nu\beta\beta$ decay $T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08\ \mathrm{fit}}\ {}^{+0.11}_{-0.06\ \mathrm{syst}}) \cdot 10^{21}$ yr.
- Results for the half-life of the $0\nu\beta\beta$ decay will be published in the coming days.
- Installation of the GERDA Phase II will be started in July 2013.

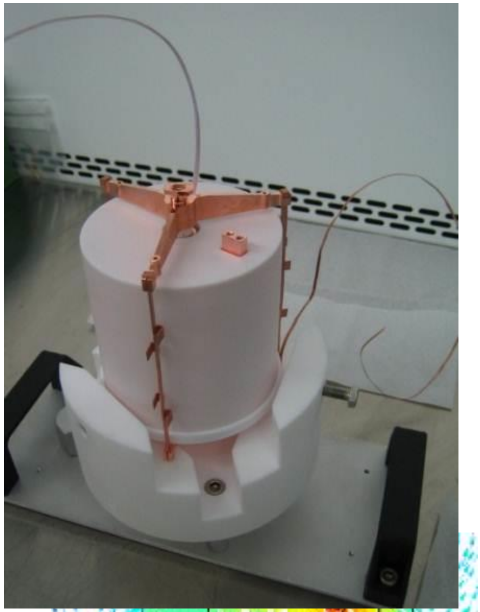
Back up slides

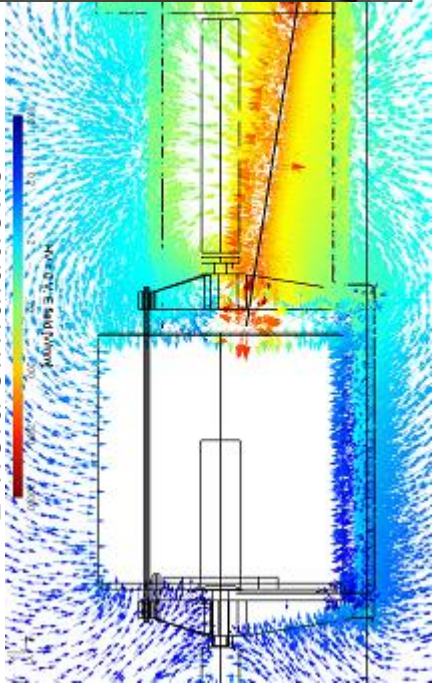
^{42}K collection by encapsulated detector

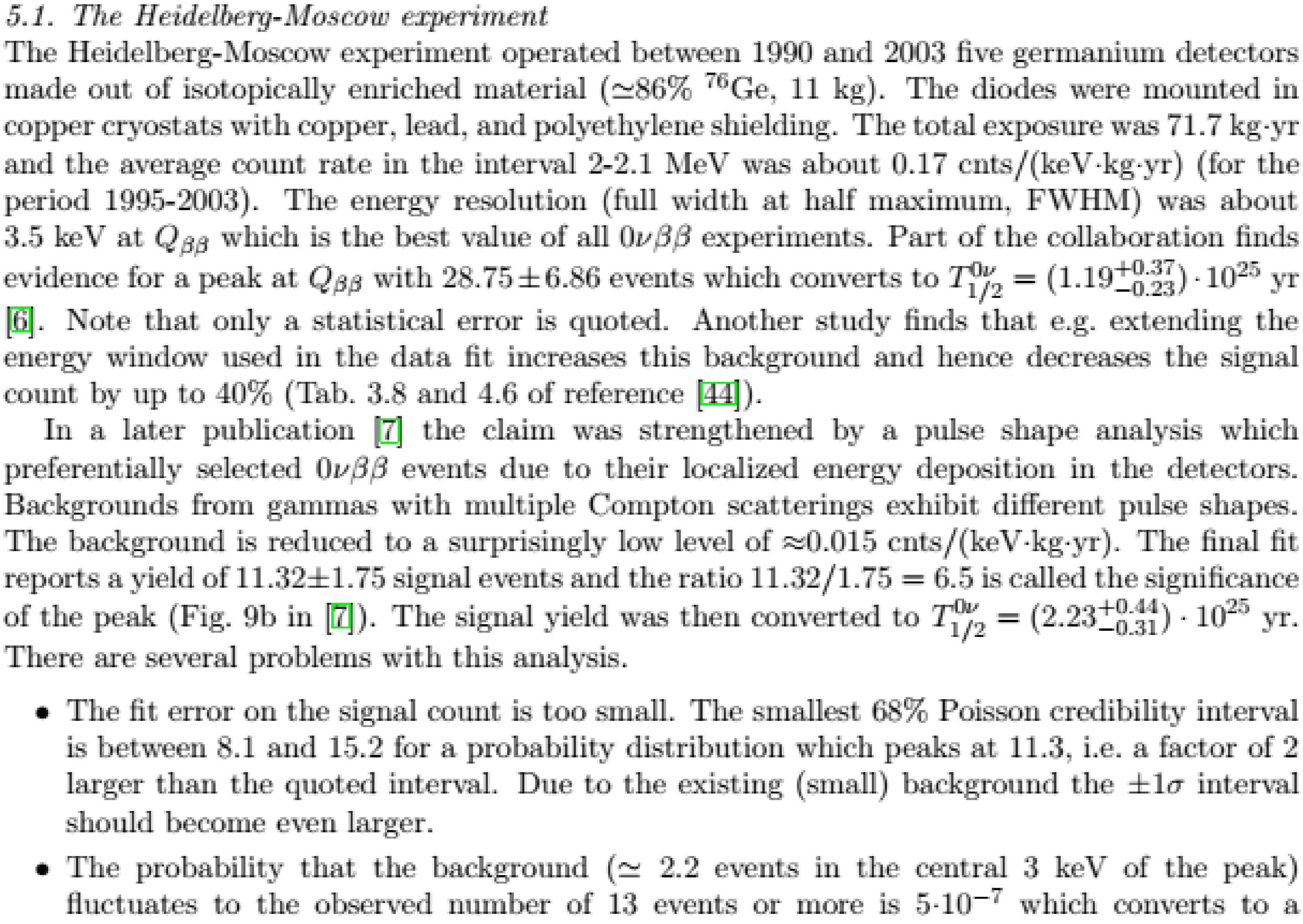
Measurements with a germanium detector have been performed in LArGe for investigation of the collection processes of ^{42}K. The detector was fully **encapsulated** by a PTFE/Cu/PTFE sandwich. It is possible to apply positive/negative HV on the encapsulation and study of collection ^{42}K ions by electric field.


Dependence of the count rates of ^{42}K from applied HV on the encapsulation

Preliminary results on the ^{42}Ar activity in natural LAr:
(65.6 ± 3.7$_{stat}$± 13.5$_{sys}$) μBq/kg
from GERDA analysis:
(92.8 ± 6.9) μBq/kg




E-field simulations



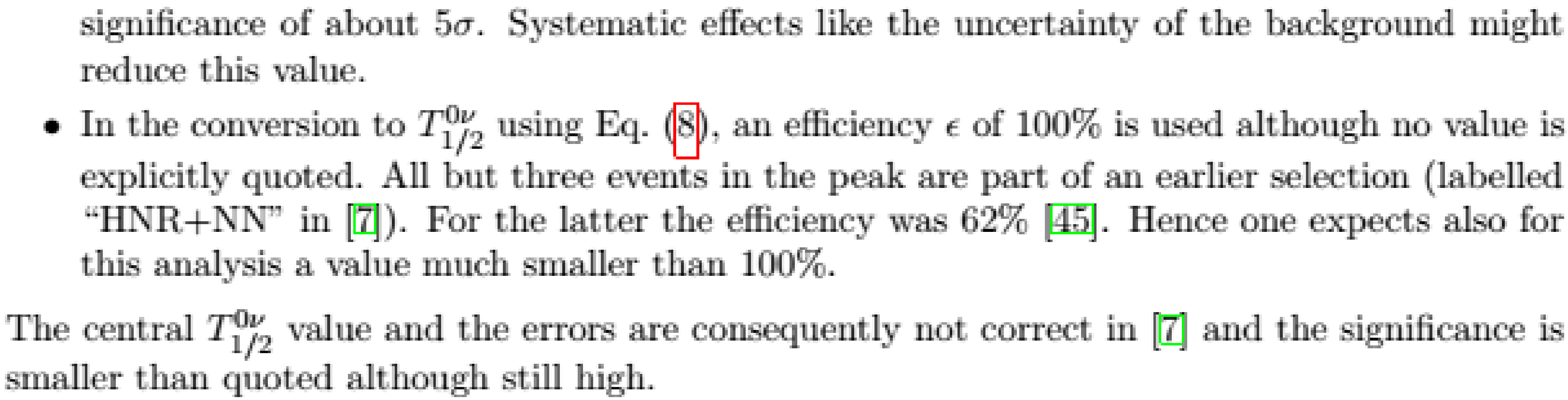
5.1. *The Heidelberg-Moscow experiment*

The Heidelberg-Moscow experiment operated between 1990 and 2003 five germanium detectors made out of isotopically enriched material ($\simeq$86% ^{76}Ge, 11 kg). The diodes were mounted in copper cryostats with copper, lead, and polyethylene shielding. The total exposure was 71.7 kg·yr and the average count rate in the interval 2-2.1 MeV was about 0.17 cnts/(keV·kg·yr) (for the period 1995-2003). The energy resolution (full width at half maximum, FWHM) was about 3.5 keV at $Q_{\beta\beta}$ which is the best value of all $0\nu\beta\beta$ experiments. Part of the collaboration finds evidence for a peak at $Q_{\beta\beta}$ with 28.75 ± 6.86 events which converts to $T^{0\nu}_{1/2} = (1.19^{+0.37}_{-0.23}) \cdot 10^{25}$ yr [6]. Note that only a statistical error is quoted. Another study finds that e.g. extending the energy window used in the data fit increases this background and hence decreases the signal count by up to 40% (Tab. 3.8 and 4.6 of reference [44]).

In a later publication [7] the claim was strengthened by a pulse shape analysis which preferentially selected $0\nu\beta\beta$ events due to their localized energy deposition in the detectors. Backgrounds from gammas with multiple Compton scatterings exhibit different pulse shapes. The background is reduced to a surprisingly low level of $\approx$0.015 cnts/(keV·kg·yr). The final fit reports a yield of 11.32 ± 1.75 signal events and the ratio $11.32/1.75 = 6.5$ is called the significance of the peak (Fig. 9b in [7]). The signal yield was then converted to $T^{0\nu}_{1/2} = (2.23^{+0.44}_{-0.31}) \cdot 10^{25}$ yr. There are several problems with this analysis.

- The fit error on the signal count is too small. The smallest 68% Poisson credibility interval is between 8.1 and 15.2 for a probability distribution which peaks at 11.3, i.e. a factor of 2 larger than the quoted interval. Due to the existing (small) background the $\pm 1\sigma$ interval should become even larger.
- The probability that the background ($\simeq$ 2.2 events in the central 3 keV of the peak) fluctuates to the observed number of 13 events or more is $5 \cdot 10^{-7}$ which converts to a

Taken from Ann. Phys., 525: 269–280

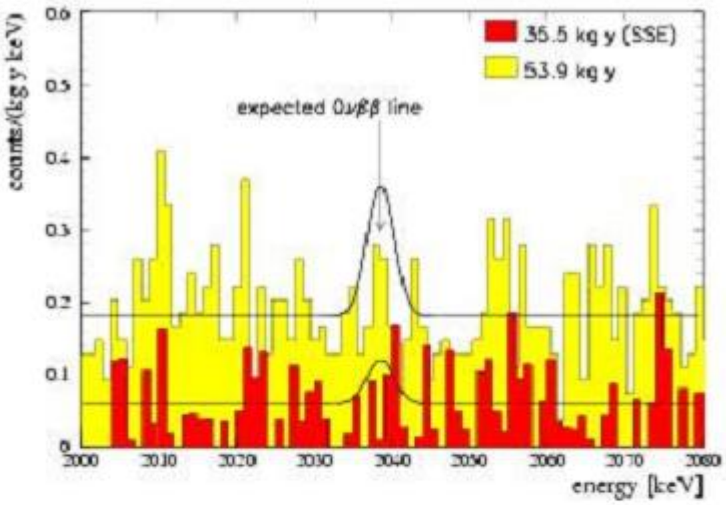


significance of about 5σ. Systematic effects like the uncertainty of the background might reduce this value.

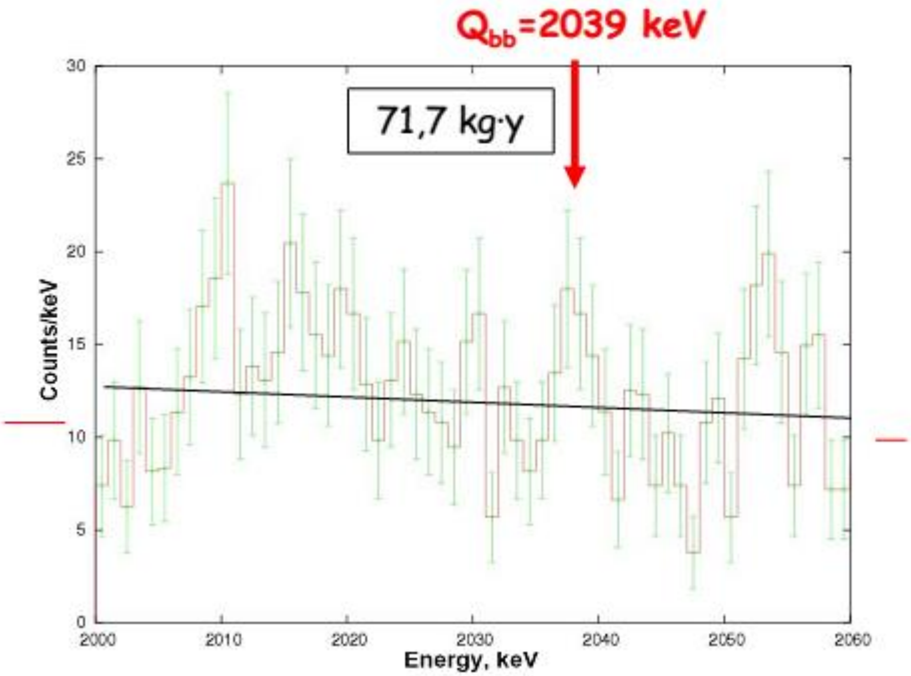
- In the conversion to $T^{0\nu}_{1/2}$ using Eq. (8), an efficiency ϵ of 100% is used although no value is explicitly quoted. All but three events in the peak are part of an earlier selection (labelled "HNR+NN" in [7]). For the latter the efficiency was 62% [45]. Hence one expects also for this analysis a value much smaller than 100%.

The central $T^{0\nu}_{1/2}$ value and the errors are consequently not correct in [7] and the significance is smaller than quoted although still high.

Evidence??



N_{Bkg} $\begin{cases} 0{,}19 \text{ counts } y^{-1}\, kg^{-1}\, keV^{-1} \\ 0{,}06 \text{ counts } y^{-1}\, kg^{-1}\, keV^{-1} \text{ (SSE)} \end{cases}$



Taken from Ann. Phys., 525: 269–280

Background around ROI

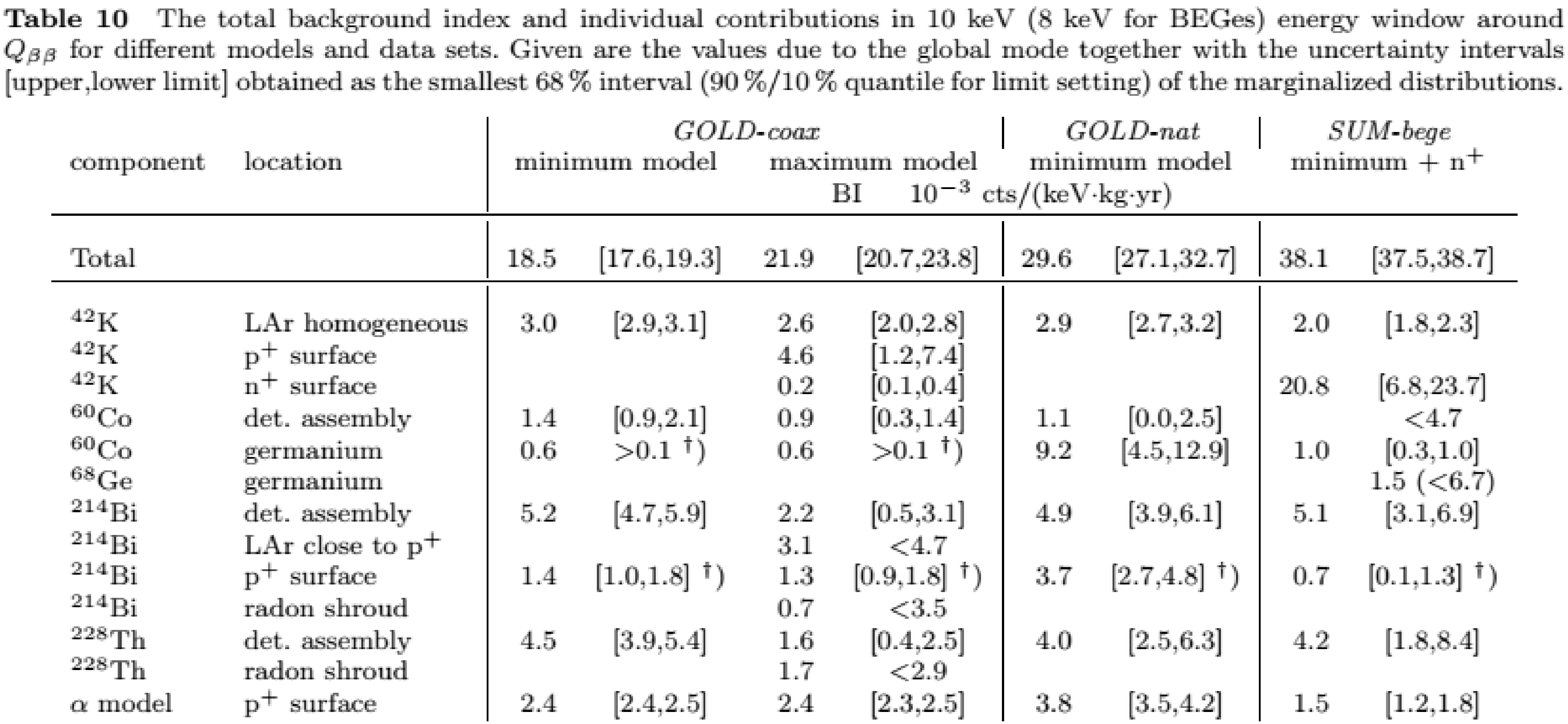


Table 10 The total background index and individual contributions in 10 keV (8 keV for BEGes) energy window around $Q_{\beta\beta}$ for different models and data sets. Given are the values due to the global mode together with the uncertainty intervals [upper,lower limit] obtained as the smallest 68 % interval (90 %/10 % quantile for limit setting) of the marginalized distributions.

component	location	*GOLD-coax* minimum model		*GOLD-coax* maximum model		*GOLD-nat* minimum model		*SUM-bege* minimum + n^+	
		BI 10^{-3} cts/(keV·kg·yr)							
Total		18.5	[17.6,19.3]	21.9	[20.7,23.8]	29.6	[27.1,32.7]	38.1	[37.5,38.7]
^{42}K	LAr homogeneous	3.0	[2.9,3.1]	2.6	[2.0,2.8]	2.9	[2.7,3.2]	2.0	[1.8,2.3]
^{42}K	p^+ surface			4.6	[1.2,7.4]				
^{42}K	n^+ surface			0.2	[0.1,0.4]			20.8	[6.8,23.7]
^{60}Co	det. assembly	1.4	[0.9,2.1]	0.9	[0.3,1.4]	1.1	[0.0,2.5]		<4.7
^{60}Co	germanium	0.6	>0.1 †)	0.6	>0.1 †)	9.2	[4.5,12.9]	1.0	[0.3,1.0]
^{68}Ge	germanium								1.5 (<6.7)
^{214}Bi	det. assembly	5.2	[4.7,5.9]	2.2	[0.5,3.1]	4.9	[3.9,6.1]	5.1	[3.1,6.9]
^{214}Bi	LAr close to p^+			3.1	<4.7				
^{214}Bi	p^+ surface	1.4	[1.0,1.8] †)	1.3	[0.9,1.8] †)	3.7	[2.7,4.8] †)	0.7	[0.1,1.3] †)
^{214}Bi	radon shroud			0.7	<3.5				
^{228}Th	det. assembly	4.5	[3.9,5.4]	1.6	[0.4,2.5]	4.0	[2.5,6.3]	4.2	[1.8,8.4]
^{228}Th	radon shroud			1.7	<2.9				
α model	p^+ surface	2.4	[2.4,2.5]	2.4	[2.3,2.5]	3.8	[3.5,4.2]	1.5	[1.2,1.8]

See more in http://arxiv.org/abs/1306.5084