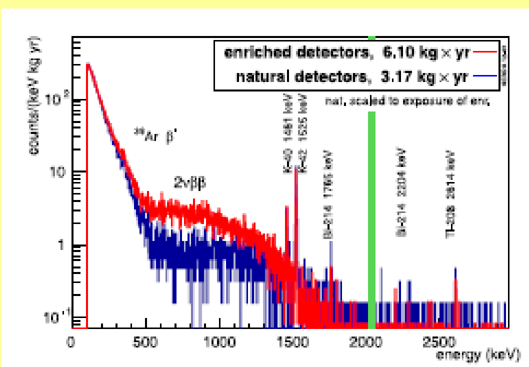
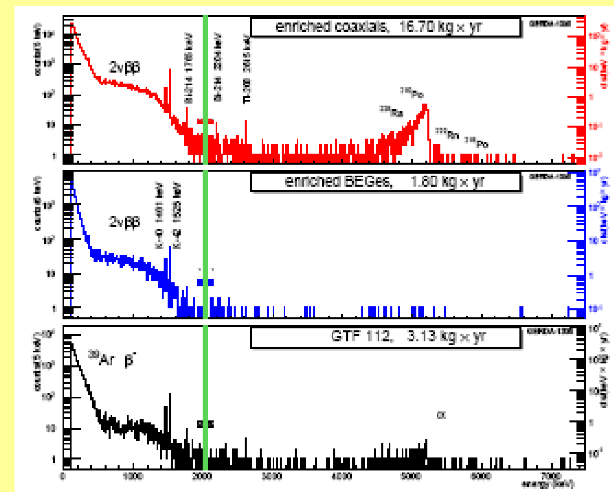
Ge detectors for GERDA Phase I and Phase II and The first GERDA results





Anatoly Smolnikov for the GERDA collaboration,

NANPino, Valday, Russia, June 24 -29, 2013

The GERDA Collaboration

K.-H. Ackermann[13], M. Agostini[14], M. Allardt[3], M. Altmann[13,b], E. Andreotti[5,18], A.M. Bakalyarov[12], M. Balata[1], I. Barabanov[10], M. Barnabé Heider[6,14,20], N. Barros[3], L. Baudis[19], C. Bauer[6], N. Becerici-Schmidt[13], E. Bellotti[7,8], S. Belogurov[11,10], S.T. Belyaev[12], G. Benato[19], A. Bettini[15,16], L. Bezrukov[10], T. Bode[14], V. Brudanin[4], R. Brugnera[15,16], D. Budjáš[14], A. Caldwell[13], C. Cattadori[8], A. Chernogorov[11], O. Chkvorets[6,21], F. Cossavella[13], A. D'Andragora[1,22], E.V. Demidova[11], A. Denisov[10], A. di Vacri[1,23], A. Domula[3], V. Egorov[4], R. Falkenstein[18], A. Ferella[19], K. Freund[18], F. Froborg[19], N. Frodyma[2], A. Gangapshev[10,6], A. Garfagnini[15,16], J. Gasparro[5,24], S. Gazzana[6,1], R. Gonzalez de Orduna[5,c], P. Grabmayr[18,a], V. Gurentsov[10], K. Gusev[12,4,14], K.K. Guthikonda[19], W. Hampel[6], A. Hegai[18], M. Heisel[6], S. Hemmer[15,16], G. Heusser[6], W. Hofmann[6], M. Hult[5], L.V. Inzhechik[10,25], L. Ioannucci[1], J. Janicskó Csáthy[14], J. Jochum[18], M. Junker[1], R. Kankanyan[6], S. Kianovsky[10], T. Kihm[6], J. Kiko[6], I.V. Kirpichnikov[11], A. Kirsch[6], A. Klimenko[4,10,6], M. Knapp[18,c], K.T. Knöpfle[6], O. Kochetov[4], V.N. Kornoukhov[11,10], K. Kröninger[13,26,27], V. Kusminov[10], M. Laubenstein[1], A. Lazzaro[14], V.I. Lebedev[12], B. Lehnert[3], D. Lenz[13,c], H. Liao[13], M. Lindner[6], I. Lippi[16], J. Liu[13,28], X. Liu[17], A. Lubashevskiy[6], B. Lubsandorzhiev[10], A.A. Machado[6], B. Majorovits[13], W. Maneschg[6], G. Marissens[5], S. Mayer[13], G. Meierhofer[18,29], I. Nemchenok[4], L. Niedermeier[18,c], S. Nisi[1], J. Oehm[6], C. O'Shaughnessy[13], L. Pandola[1], P. Peiffer[6,30], K. Pelczar[2], A. Pullia[9], S. Riboldi[9], F. Ritter[18,31], C. Rossi Alvarez[16], C. Sada[15,16], M. Salathe[6], C. Schmitt[18], S. Schönert[14], J. Schreiner[6], J. Schubert[13,c], O. Schulz[13], U. Schwan[6], B. Schwingenheuer[6], H. Seitz[13], E. Shevchik[4], M. Shirchenko[12,4], H. Simgen[6], A. Smolnikov[6], L. Stanco[16], F. Stelzer[13], H. Strecker[6], M. Tarka[19], U. Trunk[6,32], C.A. Ur[16], A.A. Vasenko[11], S. Vogt[13], O. Volynets[13], K. von Sturm[18], V. Wagner[6], M. Walter[19], A. Wegmann[6], M. Wojcik[2], E. Yanovich[10], P. Zavarise[1,33], I. Zhitnikov[4], S.V. Zhukov[12], D. Zinatulina[4], K. Zuber[3], G. Zuzel[2]

19 institutions

from 6 countries

Belgium, Germany, Italy, Poland, Russia, Switzerland

114 members

Eur. Phys. J. C (2013) 73:2330

The best limits on the Ge-76 (0νββ)-decay half-life

1.9×10^{25} *y* and 1.6×10^{25} *y*, **which correspond to | m_{ee} | < 0.3 - 1.1 eV**,

have been obtained with HPGe detectors

in the predecessor experiments Heidelberg-Moscow & IGEX

with using Enriched Germanium (86% in ^{76}Ge, $Q_{\beta\beta}$=2038,5 keV)

Moreover, the **part** of H-M Collaboration, after additional data treatment , claimed the presence of an excess of events in ROI, which they interpreted as the evidence for 0νββ observation with the best fit **$T_{1/2}$ = 1.19×10^{25} *y*, | m_{ee} | = 0.44 eV**

H.V. Klapdor-Kleingrothaus, A. Dietz, I.V. Krivosheina, O. Chkvorets, NIM A 522 (2004)

The main goal of the **GERDA** experiment

is searching for **neutrinoless double beta decay** of **^{76}Ge**

with considerable reduction of background

(and, correspondently, increasing sensitivity)

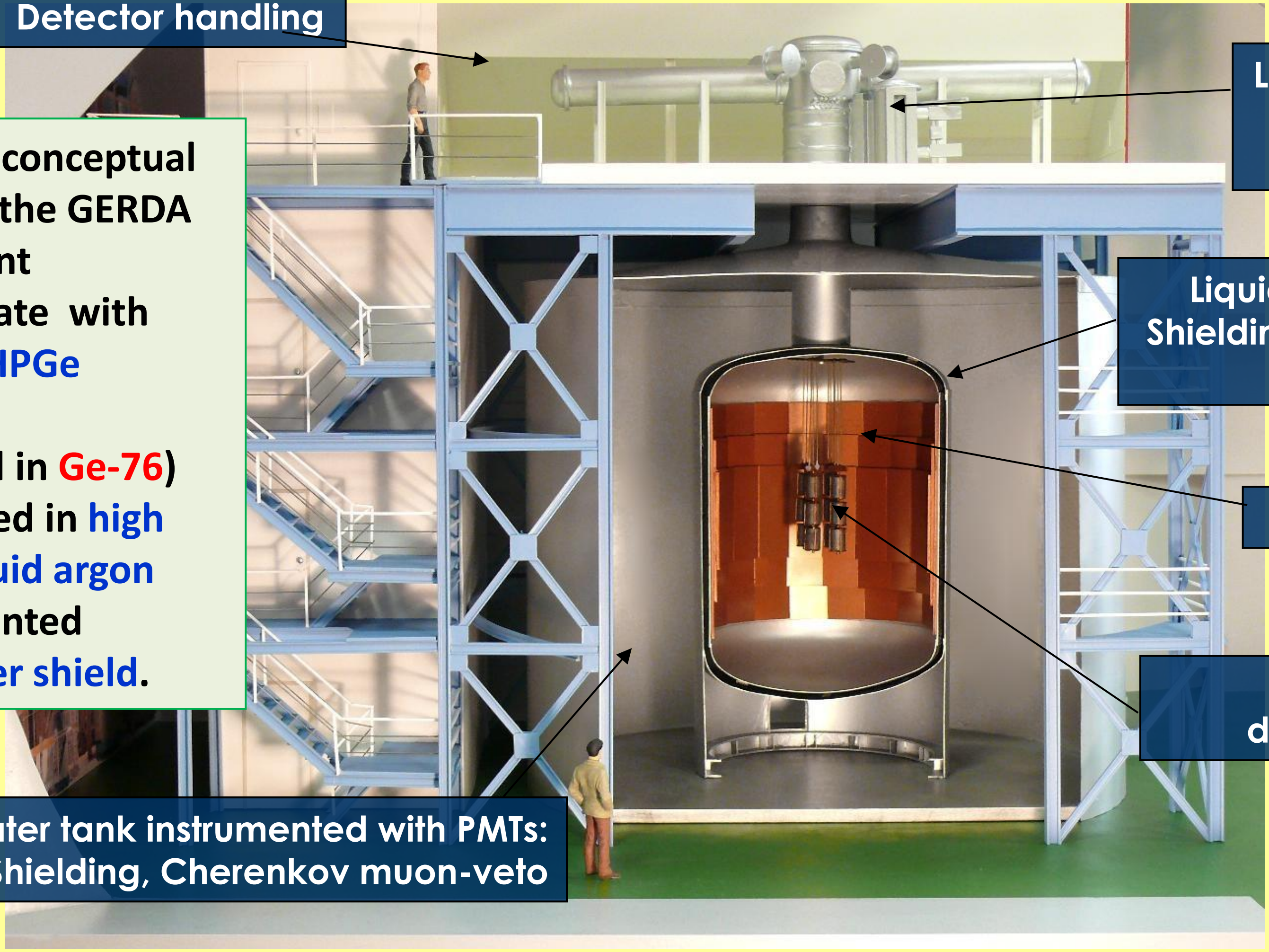
in comparison with predecessor experiments.

GERDA: the GERmanium Detector Array

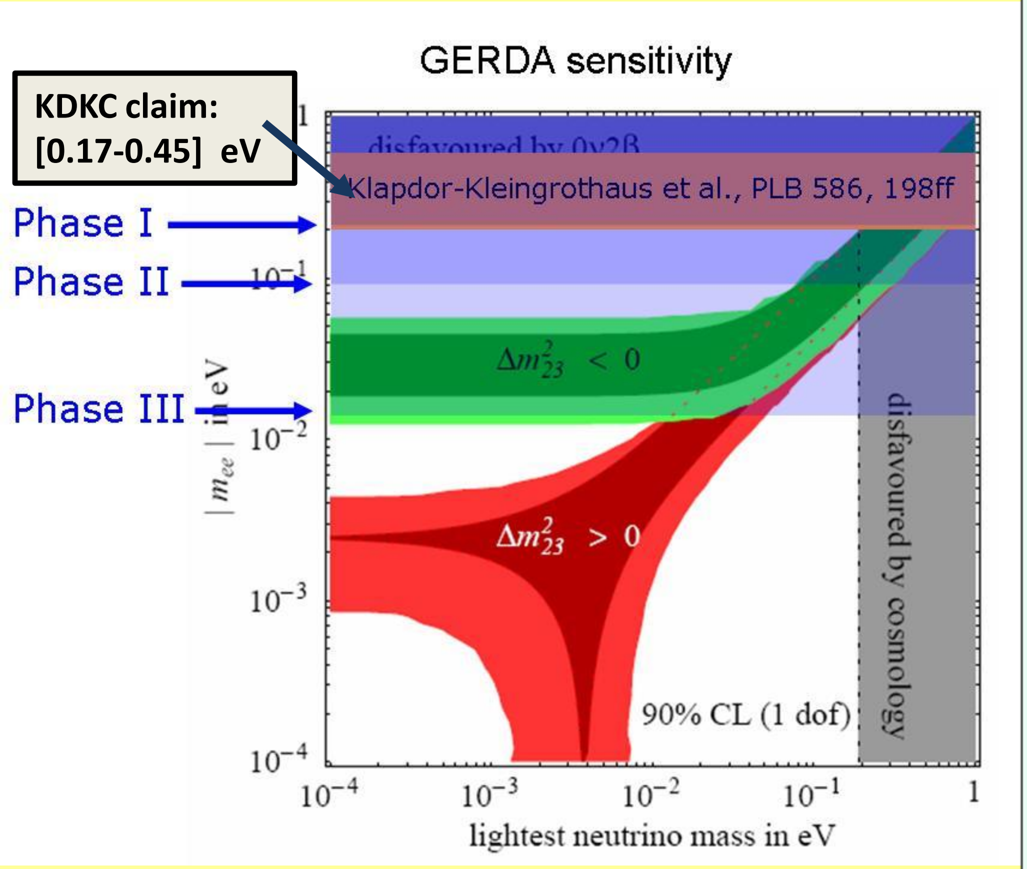
Neutrinoless Double Beta Decay Experiment

http://www.mpi-hd.mpg.de/gerda/

The main conceptual design of the GERDA experiment is to operate with "naked" HPGe detectors (enriched in Ge-76) submerged in high purity liquid argon supplemented by a water shield.



Expected sensitivity of the GERDA experiment



GERDA phase I :

background 0.01 cts / (kg · keV · y)

▶ to scrutinize KKDC result within 1 year

GERDA phase II :

background 1 cts / (ton ! · keV · y)

▶ to cover the degenerate neutrino mass hierarchy $\langle m_{ee} \rangle < 0.08 - 0.29$ eV

Phase III :

GERDA –MAJORANA collaboration

background 0.1 cts / (ton · keV · y)

▶ to cover the inverted neutrino mass hierarchy $\langle m_{ee} \rangle \sim 10$ meV

Construction of the GERDA set up
started in 2007
in Gran Sasso National Laboratory (LNGS), Italy.
Installation of the "nested type" assembly
completed in 2010
in the deep underground facility at 3400 m w.e.

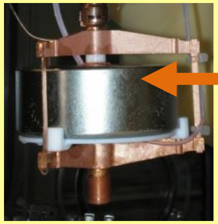
• **End of 2009**: Cryostat was filled with **95 t of liquid argon**.
Summer 2010: Water tank was filled with **565 t of ultrapure water**.
* **June 2010: Start of commissioning runs with 3 ^{nat}Ge detectors**

November 2011 – May 2013 :
Phase I physics data taking

Phase I detectors

8 enriched HPGe detectors
(in total ~ **18 kg of ^{76}Ge**)
from HdM and IGEX experiments,
6 natural HPGe detectors
(in total ~ **16 kg of ^{Nat}Ge**)
from the Genius T-F will be deployed .
All detectors **reprocessed** optimized for LAr. Energy resolution in LAr:
~2.5 keV (FWHM) @1.3 MeV
+ **5 enriched BeGe detectors**
(in total ~ **4 kg of ^{76}Ge**) – *from July 2012*

Phase II detectors



the new **30 BeGe** detectors (~ **20 kg of ^{76}Ge**) made from **enriched in ^{76}Ge material** will be added.
In total: ~ **40 kg of ^{76}Ge + 16 kg of ^{Nat}Ge**

The “nested type” assembly has been installed in the deep underground facility of LNGS, Italy

The rock overburden is equivalent to **3400 m w.e.**
This allows to reduce μ **(~ 10^6)** and neutron flux

Installation of the GERDA set up

Detector string

Glove box & lock

Clean room

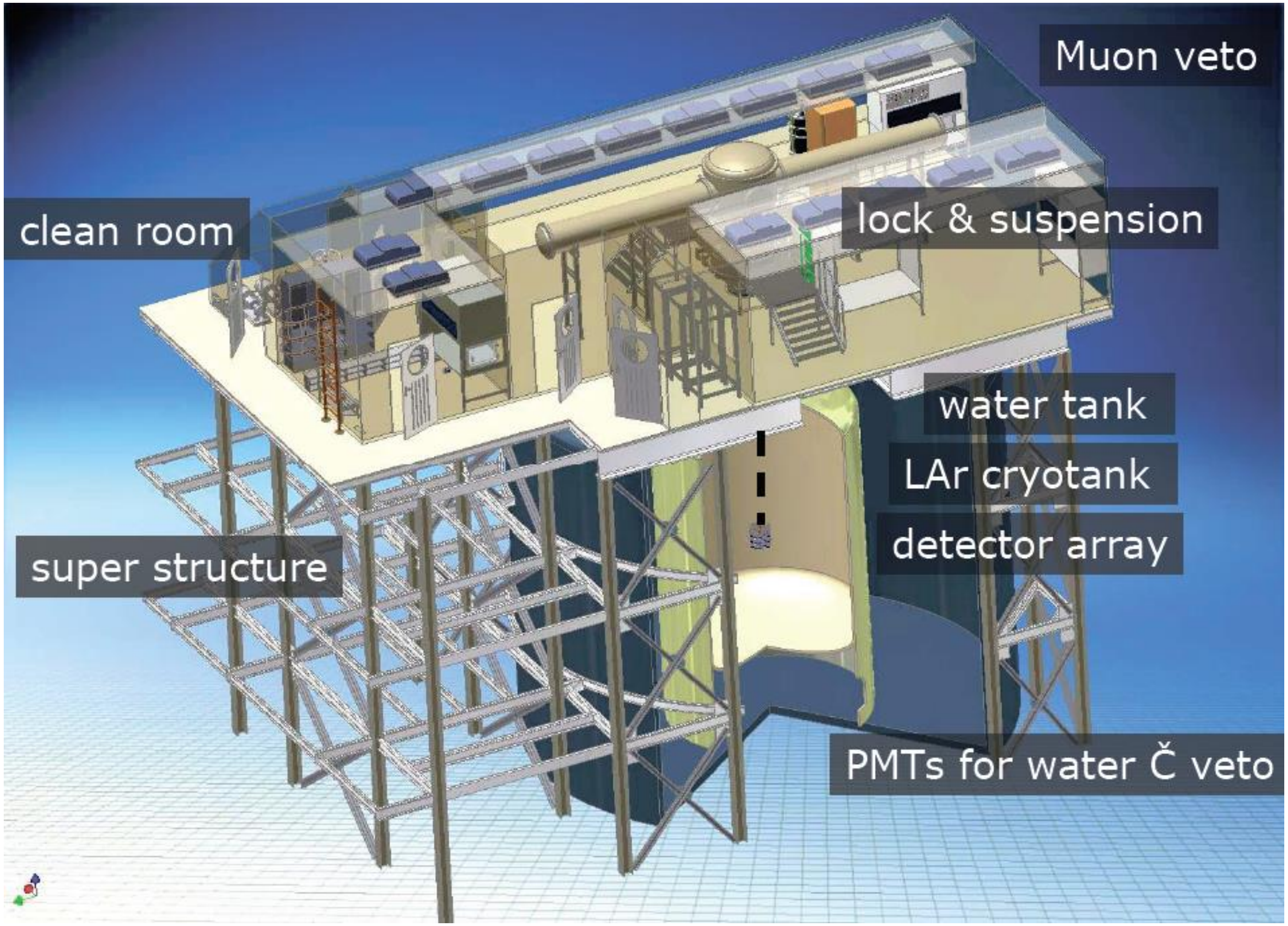
Cryostat & μ-veto

Heat exchanger & pipes

A.A. Smolnikov for the GERDA collaboration, Development and installation of the GERDA experiment, Journal of Physics: Conference Series, 203 – 012059, 1-6, 2010;

General Infrastructure of the GERDA set up

A **cleanroom** and **radon tight lock** on top of the vessel assembly allow to insert and remove individual detector strings without contaminating the cryogenic volume.



Phase I detectors

p-type coaxial HPGe detectors

Bare Ge-detector

Low-mass holder

Detector handling under N_2 atmosphere

8 from HdM, IGEX:

- Enriched 86% in ^{76}Ge
- All detectors refurbished with new contacts optimized for LAr
- Energy resolution in LAr: ~2.5 keV (FWHM) @1.3 MeV
- Well tested procedure for detector handling
- Total mass 17.66 kg (after refurbishing)

6 from Genius-TF ^{nat}Ge:

- Same refurbishing & testing as enriched diodes
- Total mass: 15.60 kg

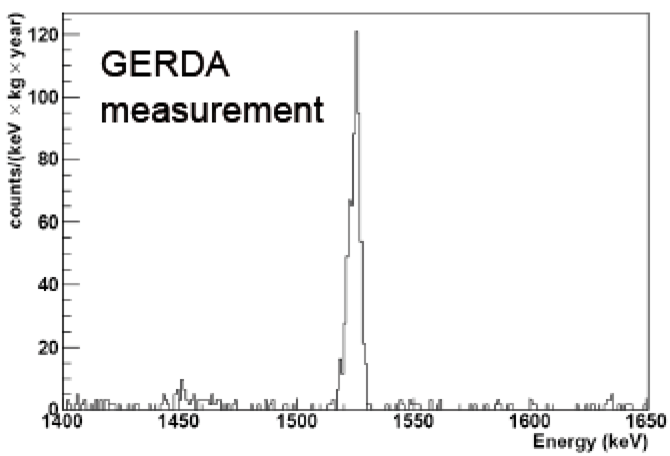
GERDA Commissioning

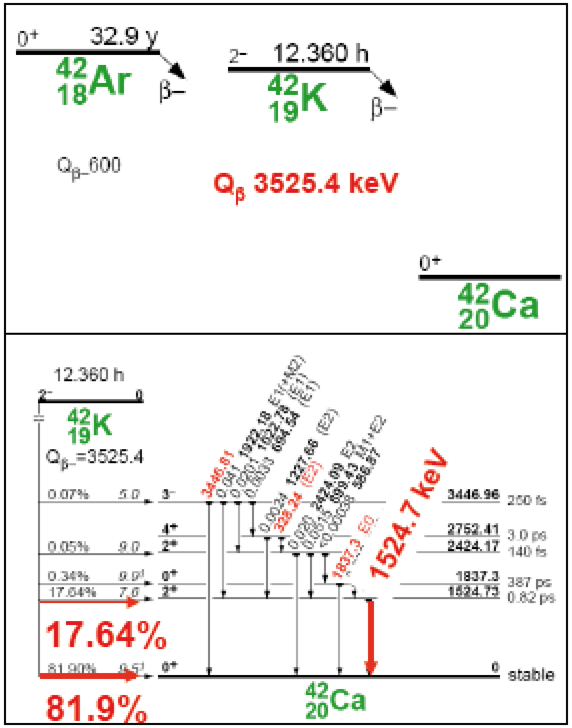
The first commissioning runs revealed a count rate due to presence of ^{42}Ar in the liquid argon significantly above the rate expected on the basis of known experimental upper limits.

The unexpected ^{42}Ar (^{42}K) Signal

GERDA proposal: $^{42}Ar/^{nat}Ar < 3\cdot10^{-21}$

[Barabash et al. 2002]





Surprise:

- True value could be x10 higher than limit
- Additional enhancement of count rate due to collection of ^{42}K ions by E-field of diodes
- If ^{42}K decay on detector surface ➔ bgd to $0\nu\beta\beta$

The GERDA collaboration investigated the ^{42}Ar issue carefully by testing different field configurations in LAr around detectors and performed 12 runs with different fields.

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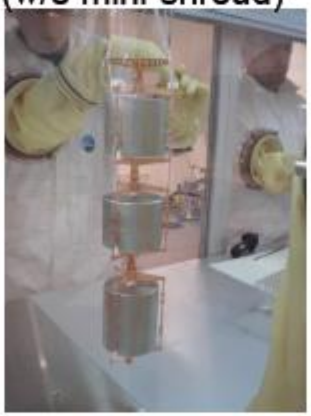
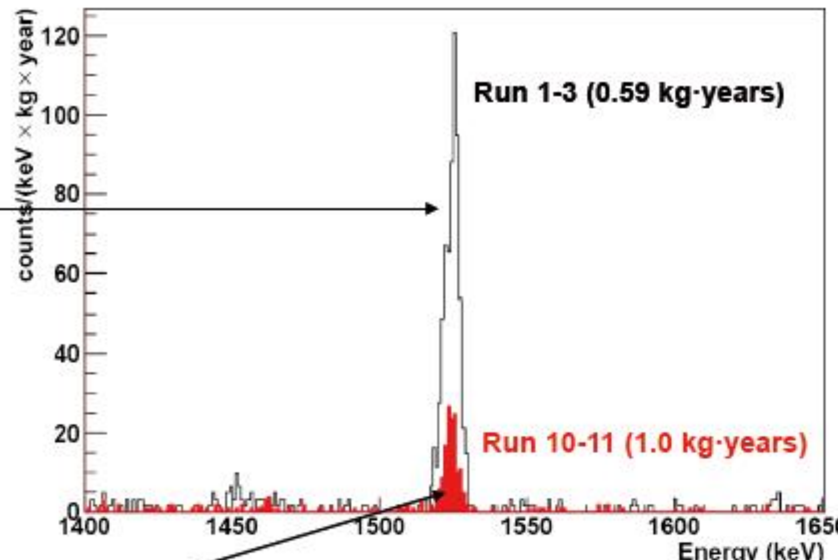
^{42}Ar (^{42}K) Counte Rate & E-Field of Detectors

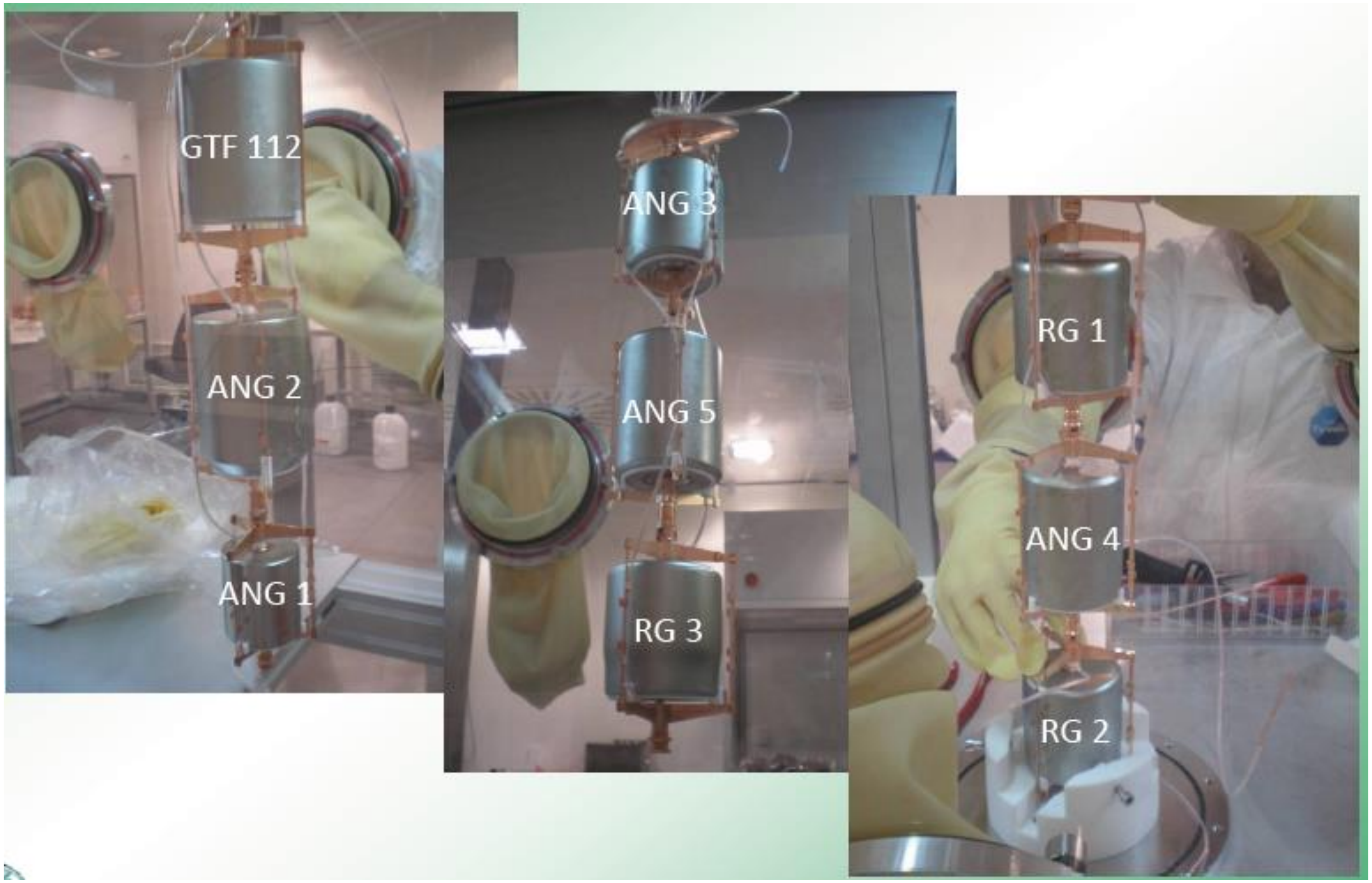
+HV on n+ contact
(w/o mini-shroud)





mini-shroud
shields
E-field &
possible
convections

The GERDA Phase I semi-coaxial enriched in Ge-76 and natural Ge detectors.



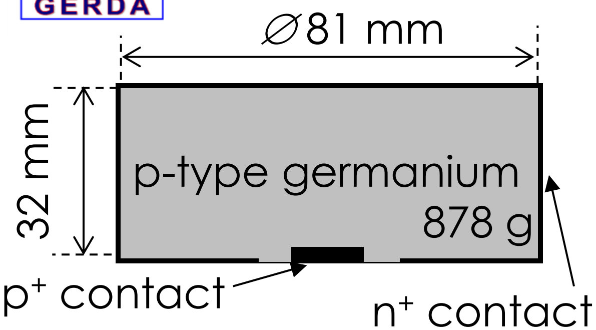
Three strings with the GERDA Phase I semi-coaxial detectors.

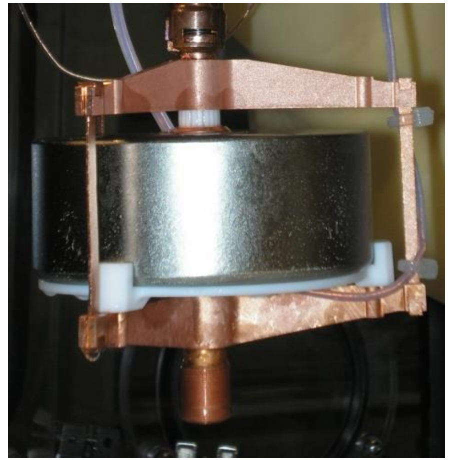
Characteristics of the GERDA Phase I semi-coaxial enriched in Ge-76 and natural Ge detectors.

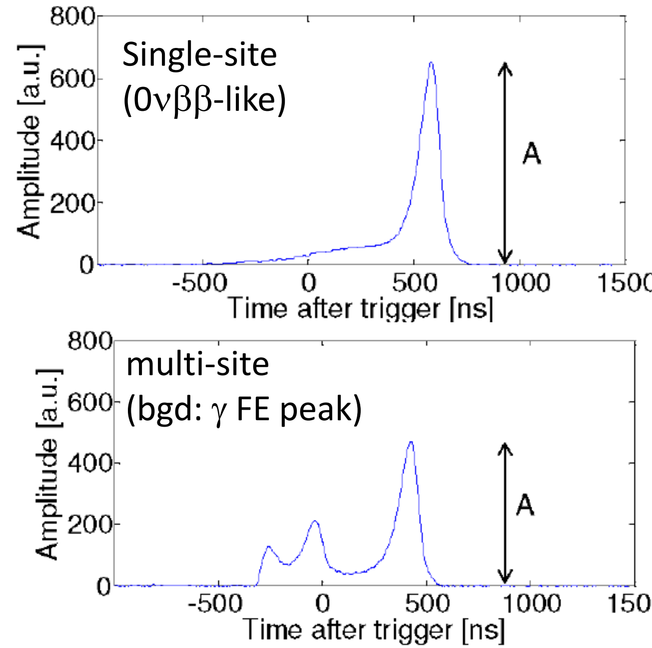
detector name	serial nr. ORTEC	diam. (mm)	length (mm)	total mass (g)	operat. bias (V)	abundance f_{76}
ANG 1	*	58.5	68	958	3200	0.859 (13)
ANG 2	P40239A	80	107	2833	3500	0.866 (25)
ANG 3	P40270A	78	93	2391	3200	0.883 (26)
ANG 4	P40368A	75	100	2372	3200	0.863 (13)
ANG 5	P40496A	78.5	105	2746	1800	0.856 (13)
RG 1†	28005-S	77.5	84	2110	4600	0.8551 (10)
RG 2†	28006-S	77.5	84	2166	4500	0.8551 (10)
RG 3†	28007-S	79	81	2087	3300	0.8551 (10)
GTF 32	P41032A	89	71	2321	3500	0.078 (1)
GTF 42	P41042A	85	82.5	2467	3000	0.078 (1)
GTF 44	P41044A	84	84	2465	3500	0.078 (1)
GTF 45	P41045A	87	75	2312	4000	0.078 (1)
GTF 110	P41110A	84	105	3046	3000	0.078 (1)
GTF 112	P41112A	85	100	2965	3000	0.078 (1)

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

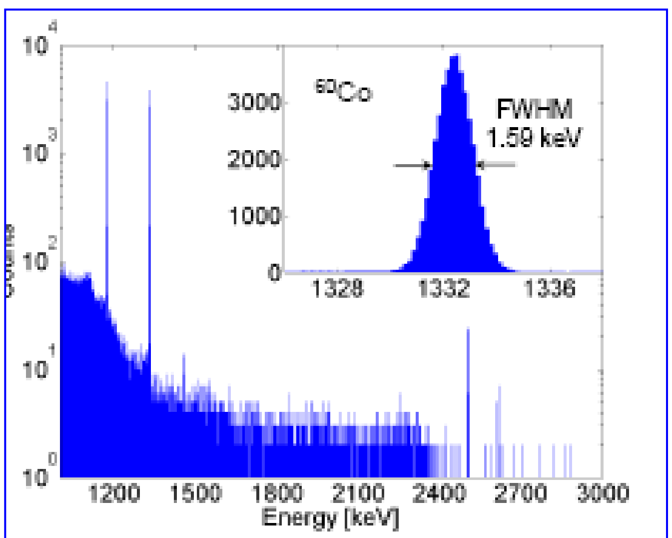
Phase II (and Phase I-b) detectors - BEGe

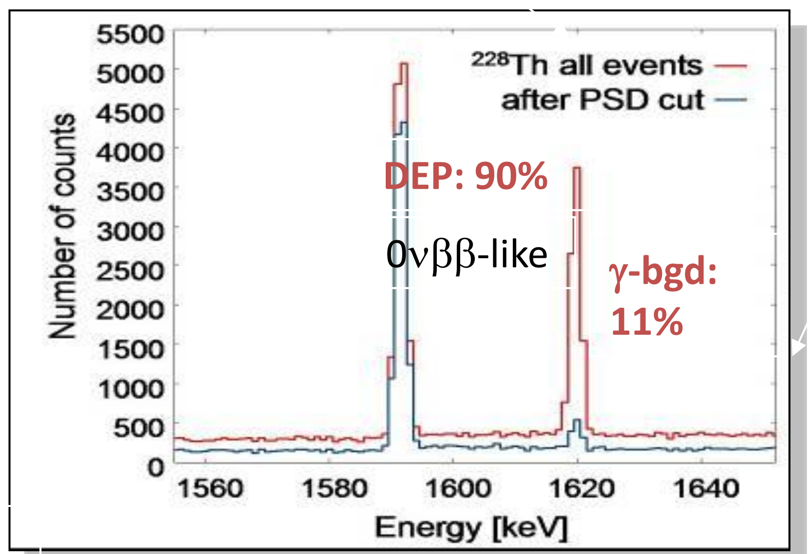




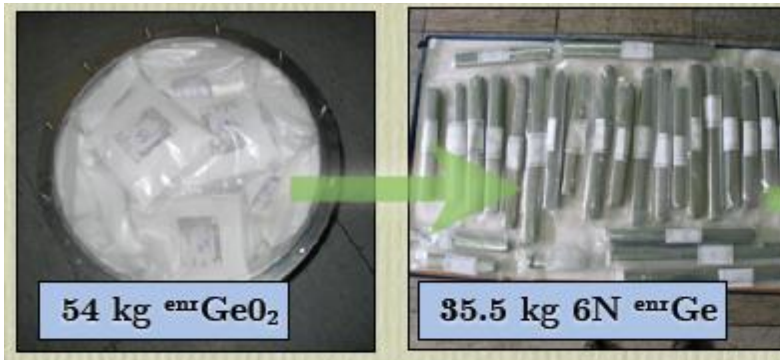


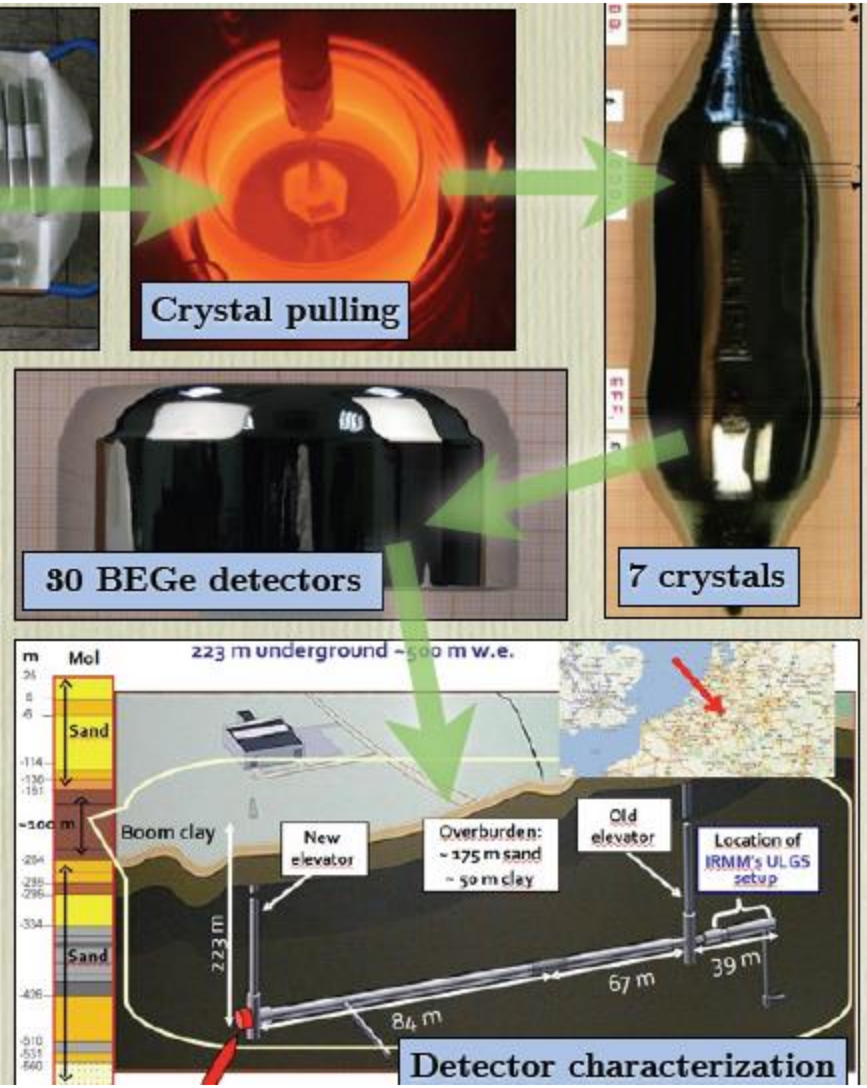
FWHM @ 59.5 keV	0.49 keV
FWHM @ 1.33 MeV	1.59 keV





Phase II (and Phase I-b) detectors - BEGe





- Whole production chain from $^{enr}GeO_2$ to BEGe diode organized by GERDA and tested with ^{dep}Ge (JINST 8 P04018 2013)
- Total gain 30 BEGes with 20.5 kg (58 % yield)
- Detector characterization in HADES underground facility, Belgium
- Exposure to cosmic rays reduced as much as possible:
  - Transport in shielded container
  - Storage and testing underground

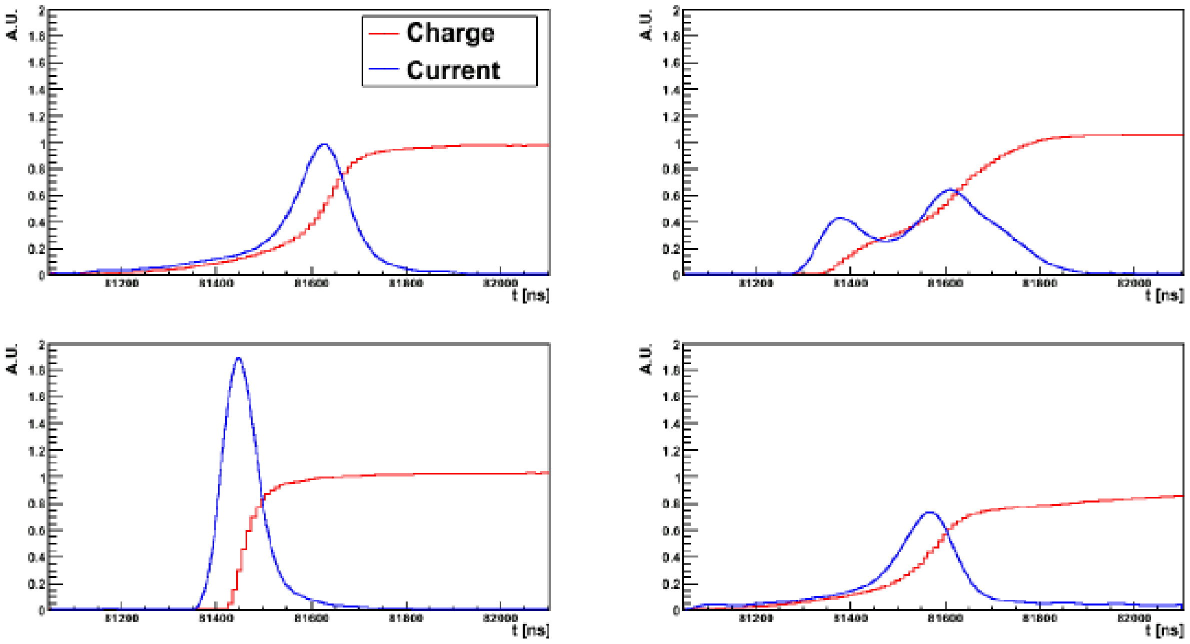
Adopted from: B.Lehnert., Talk at RICAP 13 conf., Rome, 23 May 2013

Some examples of pulse shapes

(Pulse shape discrimination for GERDA Phase I data,
to be submitted to EPJC)

A/E = Amplitude A of the current signal over the (uncalibrated) energy

SSE | MSE



p+ electrode event | n+ surface event

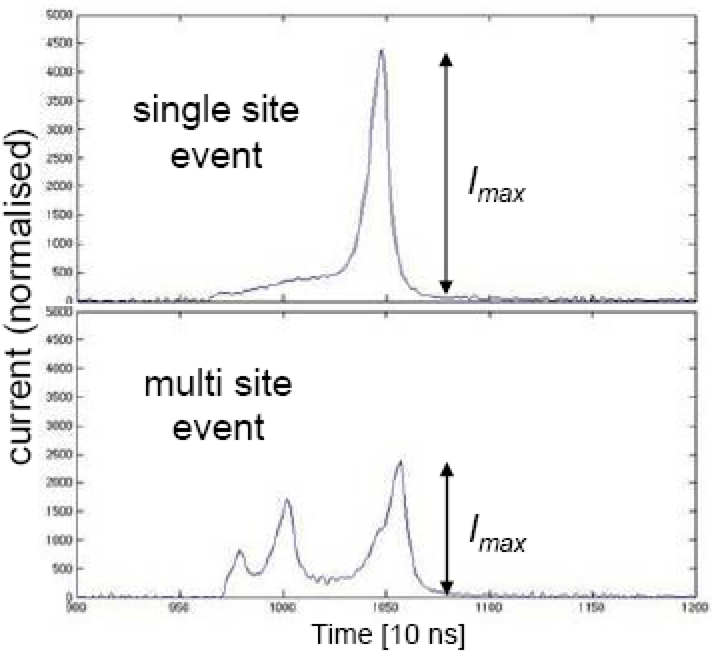
Pulse shape discrimination with BEGe

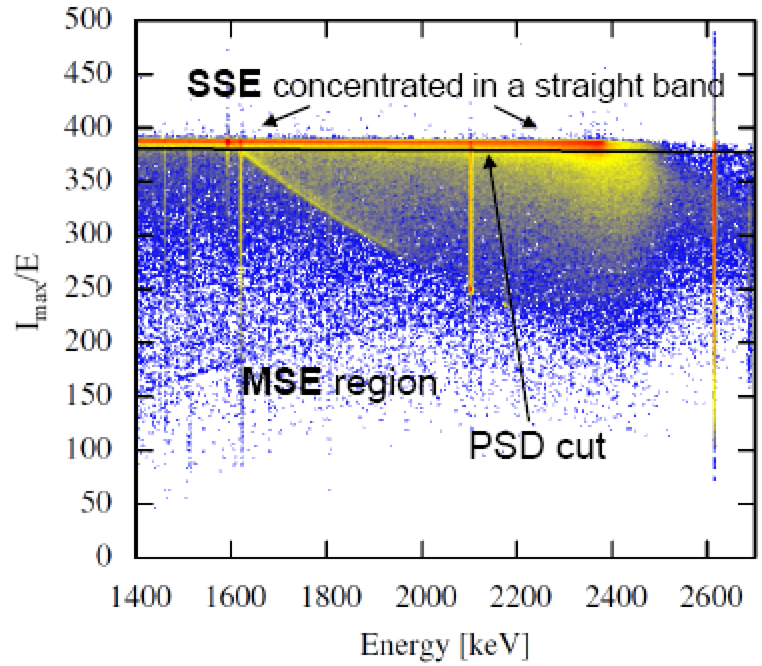
$I_{max}/E \Rightarrow$ **discrimination parameter** E=total event energy

$$I_{max} \propto q \Rightarrow$$

SSE: single charge cluster: $q \propto E \Rightarrow (I_{max}/E)_{SSE} \approx const.$

MSE: several charge clusters: $q_i < E \Rightarrow (I_{max}/E)_{MSE} < (I_{max}/E)_{SSE}$

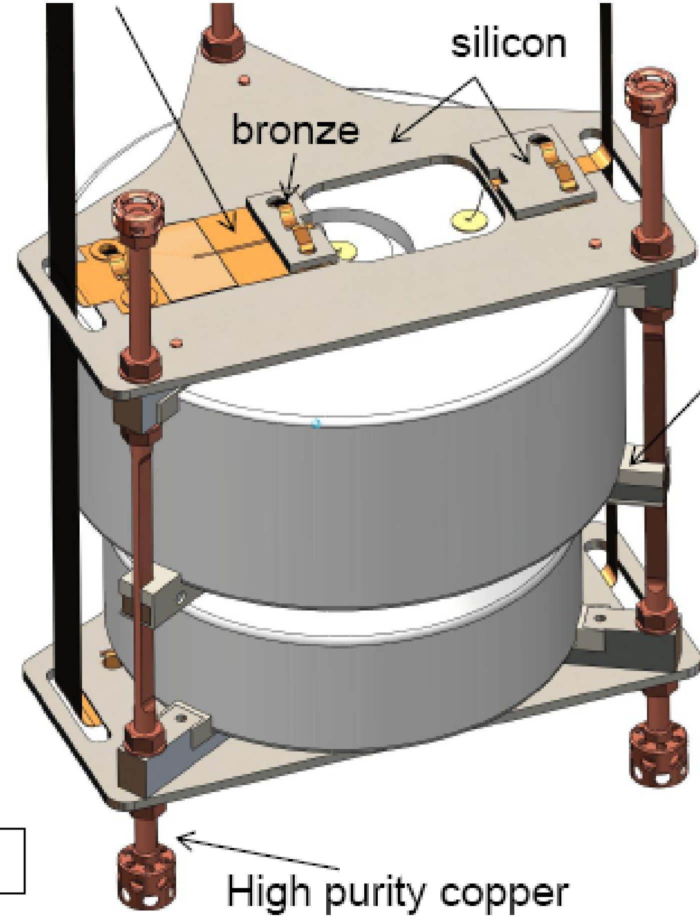




D. Budjáš et al., JINST 4:P10007,2009
M. Agostini et al., JINST 6:P03005, 2011

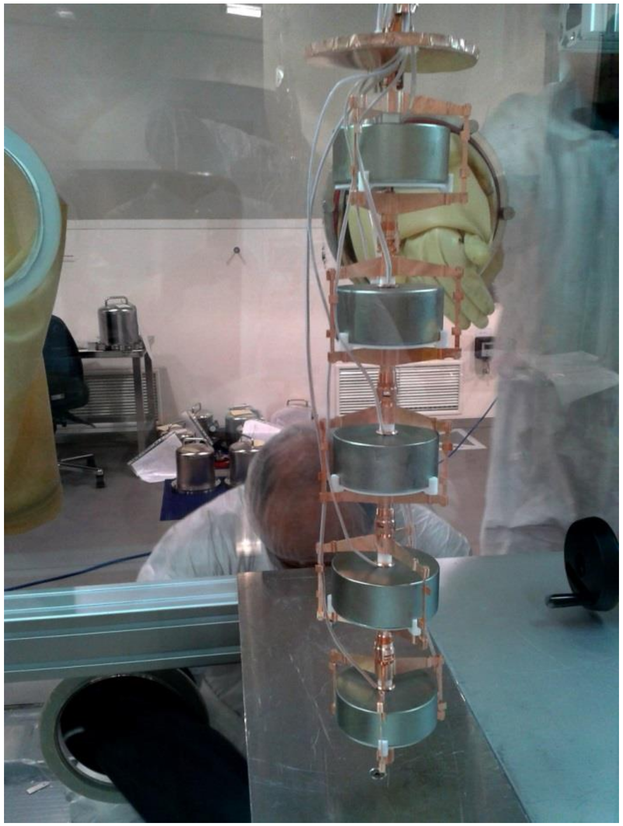
The Phase II detector mount

- Reduction of holder mass per kg detector mass necessary
  - Phase I holder: Cu 30 g/kg; PTFE 3.1 g/kg; Si 0.4 g/kg
  - Phase II holder: Cu 19 g/kg; PTFE 1.4 g/kg; Si 29 g/kg; 0.7 g/kg bronze
- Replace as much copper as possible with intrinsically pure mono crystalline silicon
- Current design achieves factor ~1.5 reduction copper & PTFE mass per kg detector mass
- New contacting scheme allows holder with reduced mass



See: T.Bode et al.,DPG-Frühjahrstagung, Dresden 2013

From July 2012 - 5 enrGe BEGe detectors (R&D for Phase II)



Detector array assembly for GERDA Phase I:

3 + 1 strings:

8 enrGe coaxial detectors
(2 not considered in the analysis)

3 natGe coaxial detectors

5 enrGe BEGe detectors

^{enr}Ge mass for physics analysis: 14.6 kg (coaxial) + 3.6 kg (BEGe)

Phase I Data taking

9 November 2011: Start of Phase I
All **8 enrGe + 3 natGe coaxial detectors** deployed in GERDA
(2 enrGe detectors are not used for analysis due to high leakage current)

7 July 2012: Insert **5 enrGe BEGe** detectors (2 natGe detectors were removed)

9 November 2011 – 21 May 2013:

558.6 days,

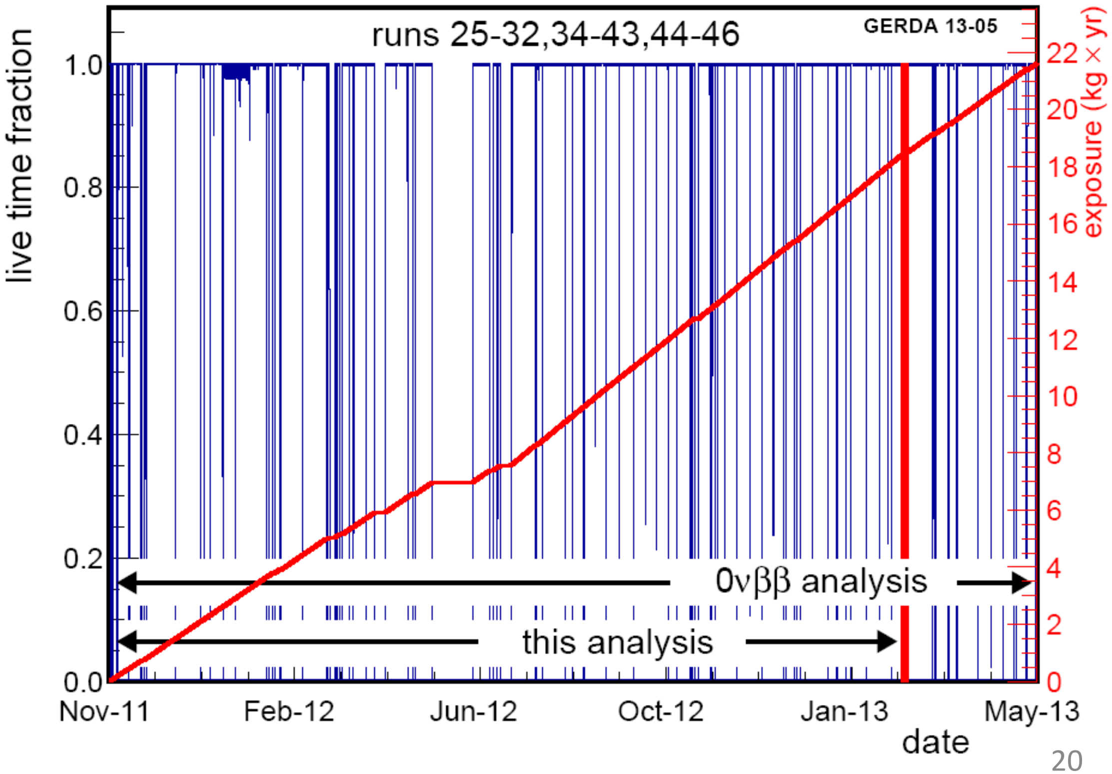
-> exposure:

Enriched Ge-76 detectors:

21.612 kg*yr,

Natural Ge detectors:

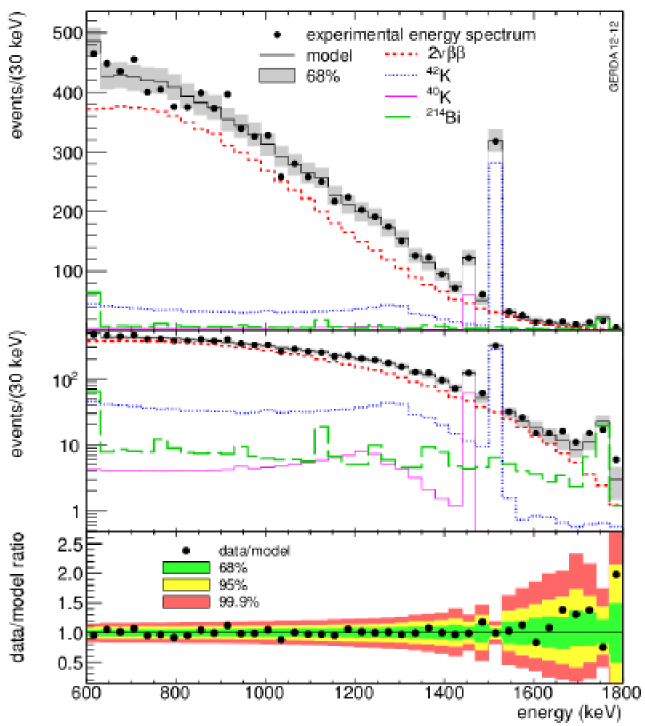
6.192 kg*yr



First 2νββ half-life results

The first 5.04 kg yr of data collected in Phase I of the experiment have been analyzed.
The observed spectrum in the energy range between 600 and 1800 keV is dominated by 2νββ decay of 76Ge.

Measurement of the half-life of the two-neutrino double beta decay of ^{76}Ge with the GERDA experiment
J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110



Signal to background: 4:1

Binned maximum likelihood

Parameters:

- Active detector masses (6+1) *nuisance parameter*
- Fraction enrichment in ^{76}Ge (6) *nuisance parameter*
- Background contributions (3×6) *nuisance parameter*
- $T^{2\nu}_{1/2}$ common to all the detectors (1)

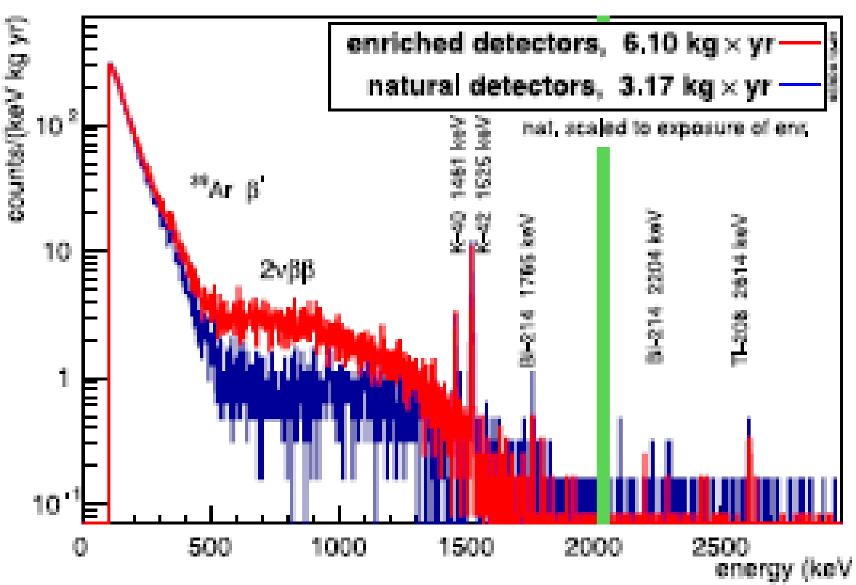
Derive $T^{2\nu}_{1/2}$ after the fit integrating over nuisance parameters

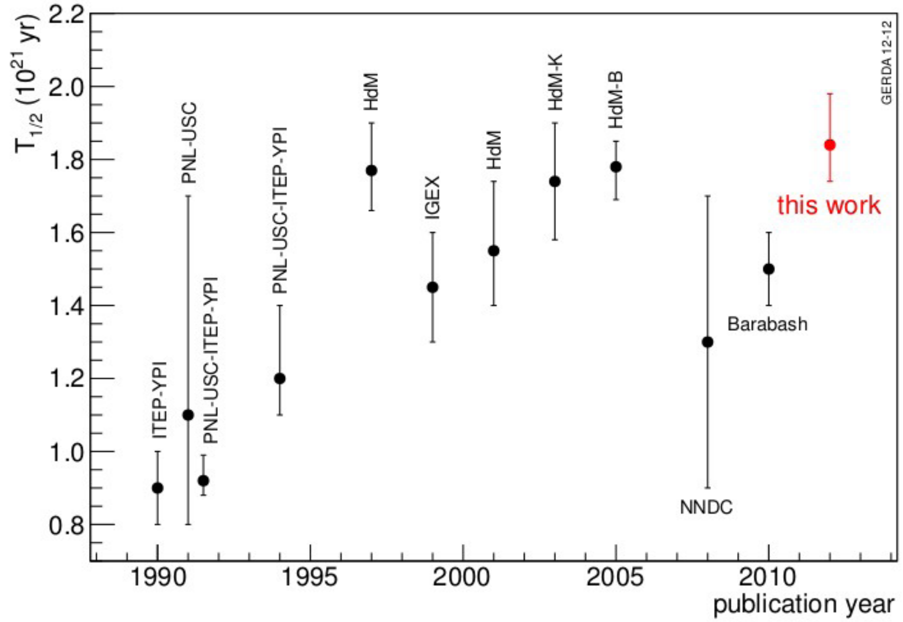
$2\nu\beta\beta$ (80%) ^{42}K (14%)
^{214}Bi (4%) ^{40}K (2%)

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

The GERDA collaboration
J. Phys. G 40 (2013) 035110

First 2νββ half-life results



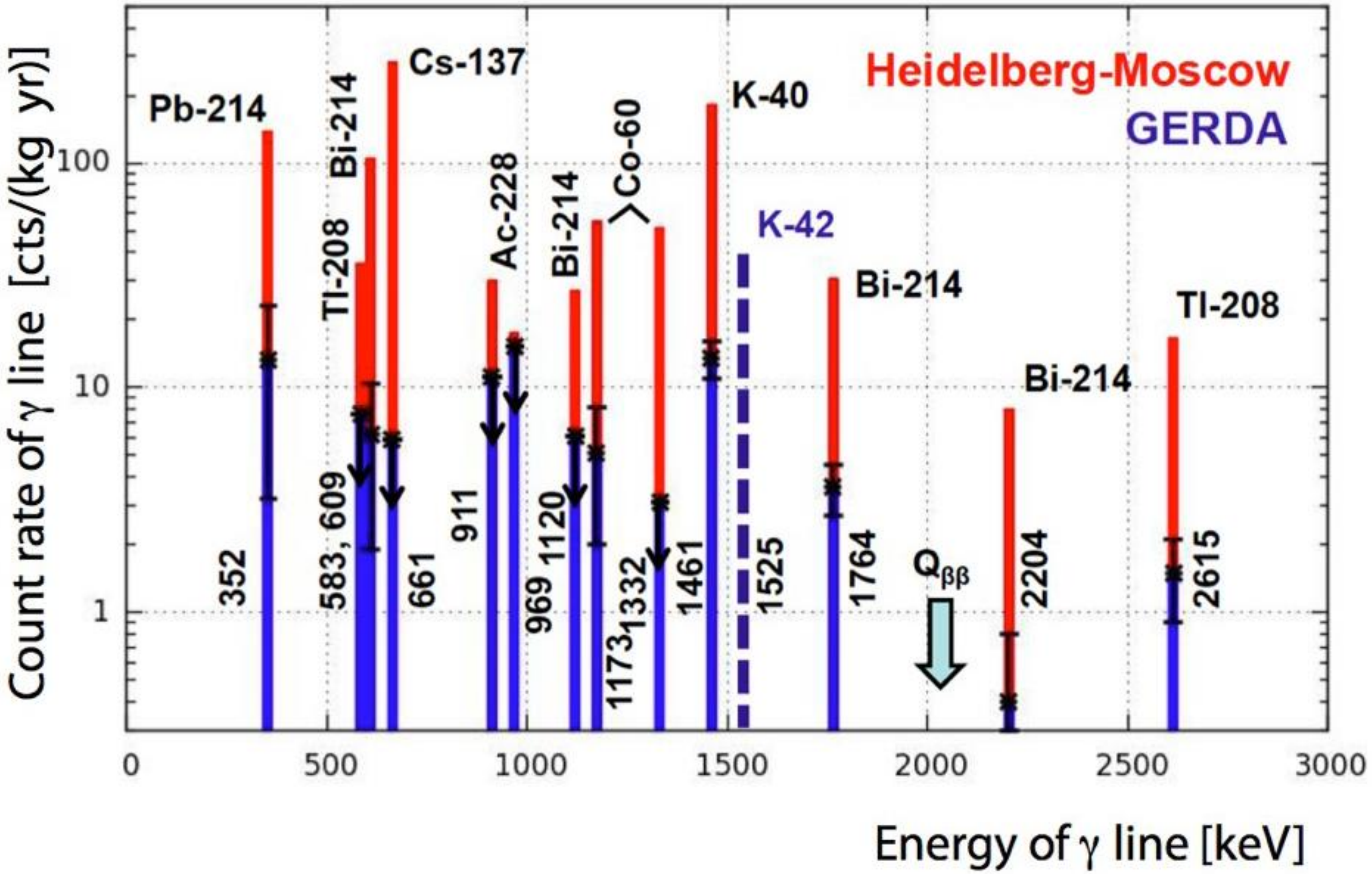


Good agreement with reanalysis of HdM data

HdM-K: Nucl. Instrum. Methods A 513, 596 (2003)

HdM-B: Phys. Part. Nucl. Lett. 2, 77 / Pisma Fiz. Elem. Chast. Atom. Yadra 2, 2005

Intensities of Gamma-peaks in comparison with Hd-M experiment



Intensities of Gamma-peaks in comparison with Hd-M experiment

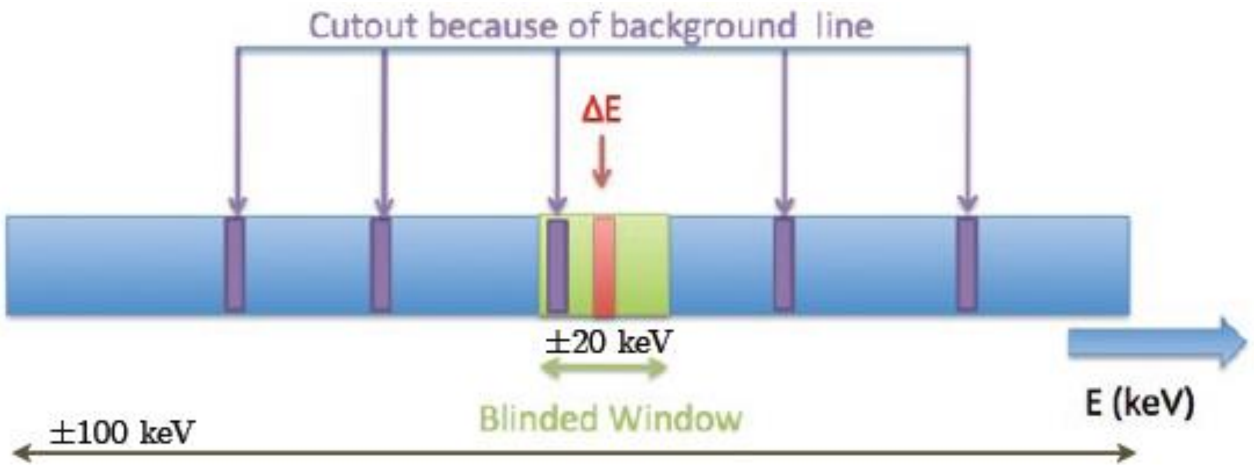
isotope	energy [keV]	^{nat}Ge (3.17 kg·yr) tot/bck [cts]	^{nat}Ge (3.17 kg·yr) rate [cts/(kg·yr)]	^{enr}Ge (6.10 kg·yr) * tot/bck [cts]	^{enr}Ge (6.10 kg·yr) * rate [cts/(kg·yr)]	HdM (71.7 kg·yr) rate [cts/(kg·yr)]	Rate HdM/ ^{enr}coaxial
^{40}K	1460.8	85 / 15	$21.7^{+3.4}_{-3.0}$	125 / 42	$13.5^{+2.2}_{-2.1}$	181 ± 2	13
^{60}Co	1173.2	43 / 38	< 5.8	182 / 152	$4.8^{+2.8}_{-2.8}$	55 ± 1	11
	1332.3	31 / 33	< 3.8	93 / 101	< 3.1	51 ± 1	
^{137}Cs	661.6	46 / 62	< 3.2	335 / 348	< 5.9	282 ± 2	>48
^{228}Ac	910.8	54 / 38	$5.1^{+2.8}_{-2.9}$	294 / 303	< 5.8	29.8 ± 1.6	
	968.9	64 / 42	$6.9^{+3.2}_{-3.2}$	247 / 230	$2.7^{+2.8}_{-2.5}$	17.6 ± 1.1	
^{208}Tl	583.2	56 / 51	< 6.5	333 / 327	< 7.6	36 ± 3	
	2614.5	9 / 2	$2.1^{+1.1}_{-1.1}$	10 / 0	$1.5^{+0.6}_{-0.5}$	16.5 ± 0.5	11
^{214}Pb	352	740 / 630	$34.1^{+12.4}_{-11.0}$	1770 / 1688	$12.5^{+9.5}_{-7.7}$	138.7 ± 4.8	11
^{214}Bi	609.3	99 / 51	$15.1^{+3.9}_{-3.9}$	351 / 311	$6.8^{+3.7}_{-4.1}$	105 ± 1	
	1120.3	71 / 44	$8.4^{+3.5}_{-3.3}$	194 / 186	< 6.1	26.9 ± 1.2	
	1764.5	23 / 5	$5.4^{+1.9}_{-1.5}$	24 / 1	$3.6^{+0.9}_{-0.8}$	30.7 ± 0.7	~10
	2204.2	5 / 2	$0.8^{+0.8}_{-0.7}$	6 / 3	$0.4^{+0.4}_{-0.4}$	8.1 ± 0.5	

The Gerda experiment for the search of 0νββdecay in 76Ge,

Eur. Phys. J. C (2013) 73:2330

See: R. Brugnera - Talk at NeuTel conference, Venice, 11-15 March 2013

0νββ **blinded data** of GERDA Phase I



1. Data after January 2012 **is blinded in ± 20 keV region around Qββ**

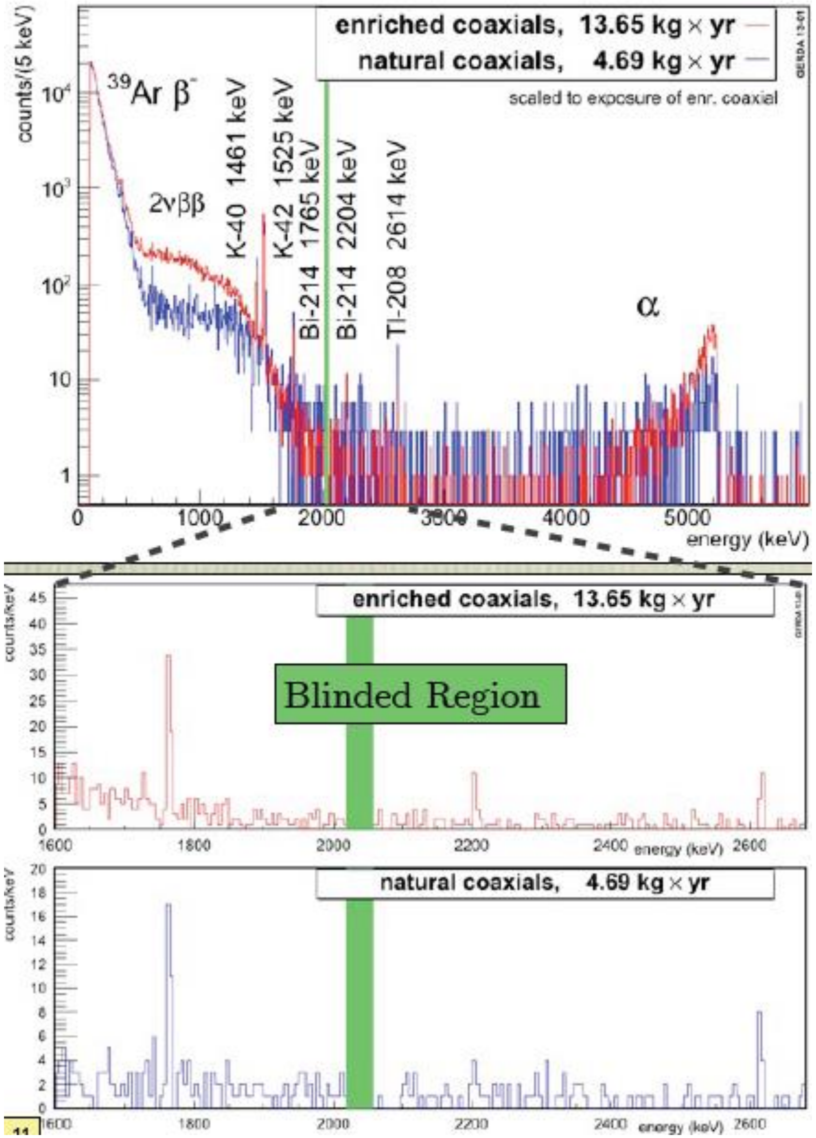
-> To avoid tuning the analysis towards signal or no-signal outcome.

2. All data processing, quality cuts and statistical analysis methods are being fixed.

-> Paper with background model and analysis parameters published on arXiv prior to final unblinding:

The background in the neutrinoless double beta decay experiment GERDA submitted to EPJC; on arXiv:1306.5084

Blinded analysis —> events at $Q_{\beta\beta} \pm 20$ keV are not available for analysis



- ^{39}Ar (up to 565 keV)
- $2\nu\beta\beta$(dominant up to 1400 keV)
- ^{40}K (γ at 1461 keV)
- ^{42}K (γ at 1525 keV)
- ^{214}Bi (γ at 1765 and 2204 keV)
- ^{208}Tl (γ at 2615 keV)
- ^{210}Po (α peak at 5.3 MeV)
- ^{226}Ra chain (cts above 5.3 MeV)

arXiv:1306.5084

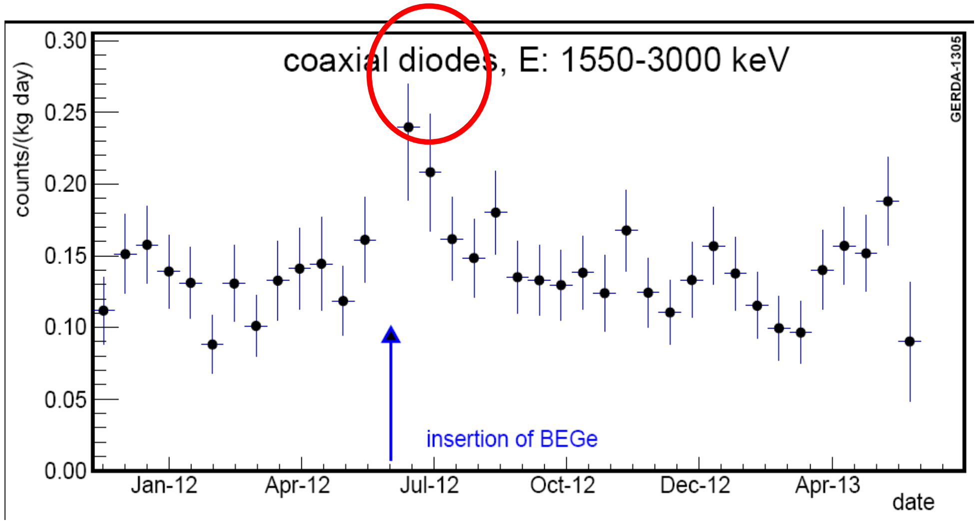
Background models and BI predictions

The **higher BI** observed after the deployment of the **BEGe detectors in July 2012** dropped to the previous level after approximately 30 days as shown in Fig.

Hence, the coaxial detector data are split:

GOLD-coax data set
contains all data except
30 days after BEGe-s deployment

SILVER-coax data set
data taken during the 30 days
after BEGe detectors deployment.

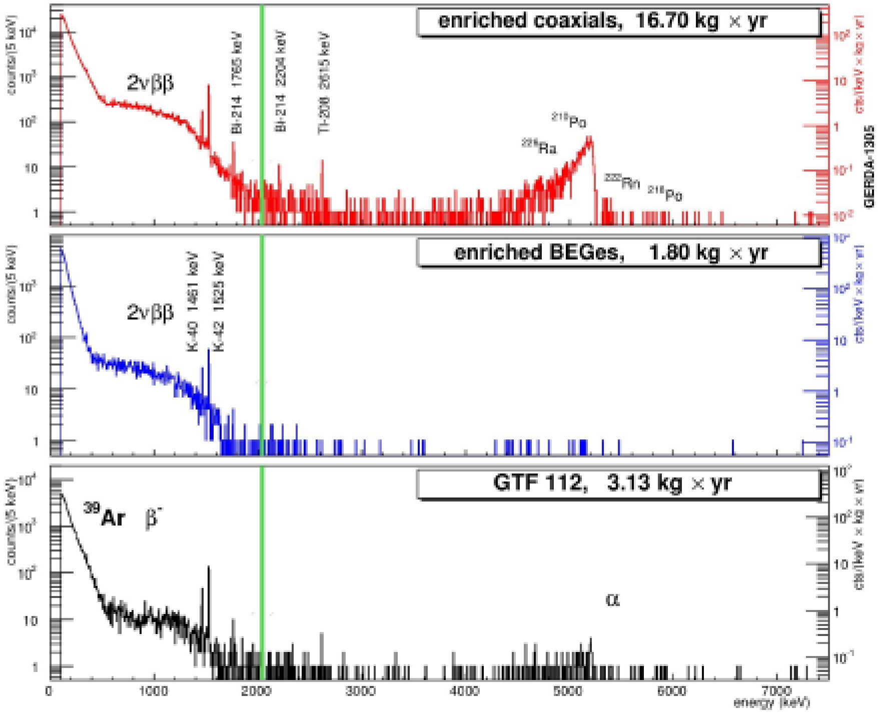


.

Fig. Time distribution of background rate of the enriched coaxial detectors in the energy range between 1550 and 3000 keV in 15 day intervals.
An increase of the BI after BEGe deployment is clearly visible.

arXiv:1306.5084

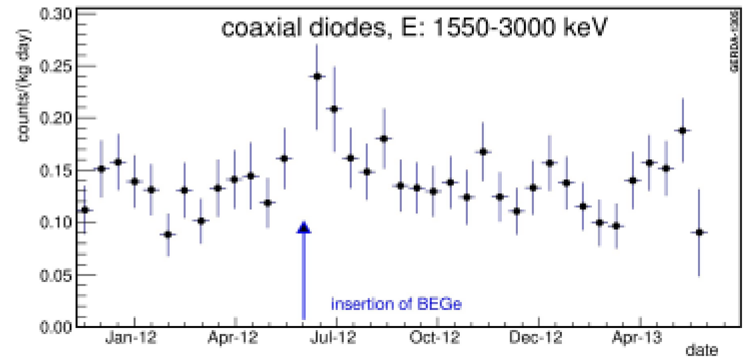
Background models and BI predictions



Considered run period
Run 25 – 43 (excl. Run 33): 417.38 days

without Runs 34 & 35
GOLD runs: 384.79 days

only Runs 34 & 35
SILVER runs: 32.59 days



data set	detectors	exposure $\mathcal{E}$ this analysis	exposure $\mathcal{E}$ $0\nu\beta\beta$ data
		kg·yr	kg·yr
SUM-coax	all enriched coaxial	16.70	19.20
GOLD-coax	all enriched coaxial	15.40	17.90
SILVER-coax	all enriched coaxial	1.30	1.30
GOLD-nat	GTF 112	3.13	3.98
GOLD-hdm	ANG 2, ANG 3, ANG 4, ANG 5	10.90	12.98
GOLD-igex	RG 1, RG 2	4.50	4.93
SUM-BEGe	GD32B, GD32C, GD32D, GD35B	1.80	2.40

BI [10^{-3} cts/(keV kg yr)]
[1930,2019] ∨ [2059,2099] ∨
[2109,2114] ∨ [2124,2190] keV

21.6 [19.1, 24.4]
17.5 [15.1, 20.1]
69.2 [53.8, 89.2]
30.4 [23.7, 38.4]
22.2 [17.8, 28.3]
15.6 [12.9, 18.5]
36.1 [26.4, 49.3]

arXiv:1306.5084

Background model components - minimum

only close sources considered

source	location	simulation	events simulated
^{210}Po	p^+ surface	ANG 3 only, $d_{dl_{p+}}$	10^9
^{226}Ra chain	p^+ surface	ANG 3 only, $d_{dl_{p+}}$	10^9
^{222}Rn chain	LAr in bore hole	ANG 3 only, $d_{dl_{p+}}$	10^9
^{214}Bi and	n^+ surface	ANG 3 only	10^8
^{214}Pb	mini-shroud	array	10^9
	detector assembly	array	10^8
	p^+ surface	ANG 3 only	10^6
	radon shroud	array	10^9
	LAr close to p^+ surface	ANG 3 only	10^6
^{208}Tl and	detector assembly	array	10^8
^{212}Bi	radon shroud	array	10^9
	heat exchanger	array	10^{10}
^{228}Ac	detector assembly	array	10^8
	radon shroud	array	10^9
^{42}K	homogeneous in LAr	array	10^9
	n^+ surface	ANG 3 only	10^8
	p^+ surface	ANG 3 only	10^6
^{60}Co	detectors	array	$2.2{\cdot}10^7$
	detector assembly	array	10^7
$2\nu\beta\beta$	detectors	array	$2.2{\cdot}10^7$
^{40}K	detector assembly	array	10^8

Alpha model

Gaussian prior on the parameter: mean and sigma given from the Ra-226 activity on p+ surface derived from alpha model

Strict range for the parameter due to activation history of enriched coax (in backup): flat prior [0, 2.3] µBq for *GOLD-coax*

arXiv:1306.5084

GERDA

Background model components - maximum

more close sources and also far sources considered

source	location	simulation	events simulated
^{210}Po	p^+ surface	ANG 3 only, $d_{dl_{p+}}$	10^9
^{226}Ra chain	p^+ surface	ANG 3 only, $d_{dl_{p+}}$	10^9
^{222}Rn chain	LAr in bore hole	ANG 3 only, $d_{dl_{p+}}$	10^9
^{214}Bi and ^{214}Pb	n^+ surface	ANG 3 only	10^8
	mini-shroud	array	10^9
	detector assembly	array	10^8
	p^+ surface	ANG 3 only	10^6
	radon shroud	array	10^9
	LAr close to p^+ surface	ANG 3 only	10^6
^{208}Tl and ^{212}Bi	detector assembly	array	10^8
	radon shroud	array	10^9
	heat exchanger	array	10^{10}
^{228}Ac	detector assembly	array	10^8
	radon shroud	array	10^9
^{42}K	homogeneous in LAr	array	10^9
	n^+ surface	ANG 3 only	10^8
	p^+ surface	ANG 3 only	10^6
^{60}Co	detectors	array	$2.2\cdot10^7$
	detector assembly	array	10^7
$2\nu\beta\beta$	detectors	array	$2.2\cdot10^7$
^{40}K	detector assembly	array	10^8

Alpha model

Gaussian prior on the parameter: mean and sigma given from the Ra-226 activity on p+ surface derived from alpha model

Strict range for the parameter due to activation history of enriched coax (in backup): flat prior [0, 2.3] µBq for *GOLD-coax*

Alpha induced event model

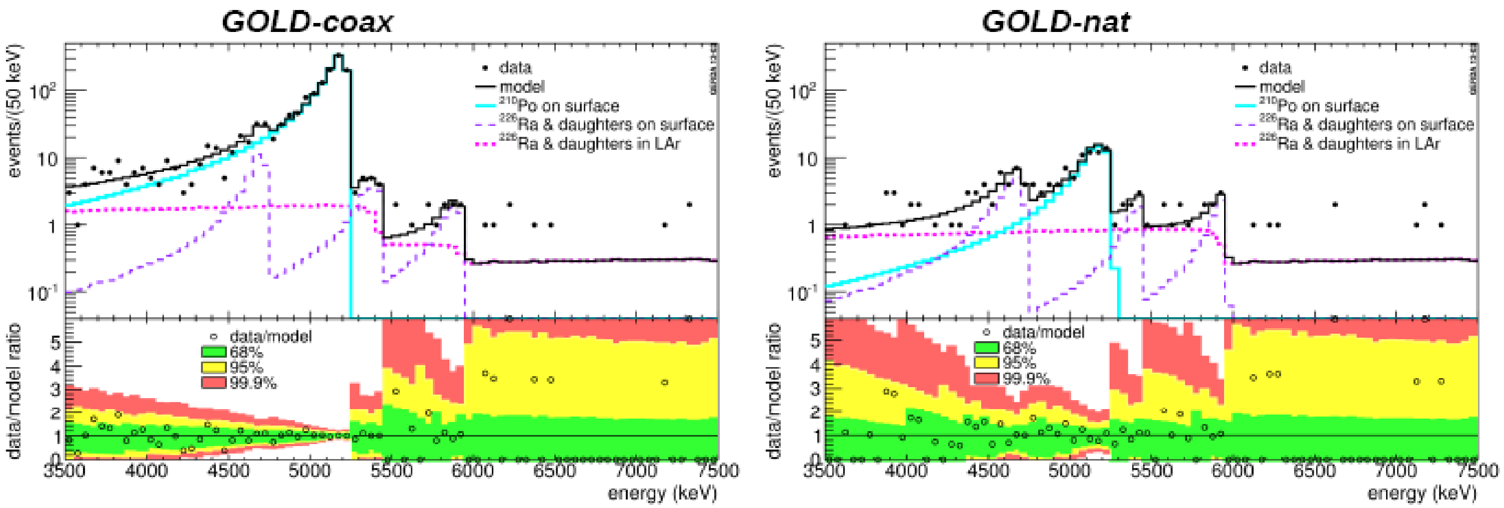


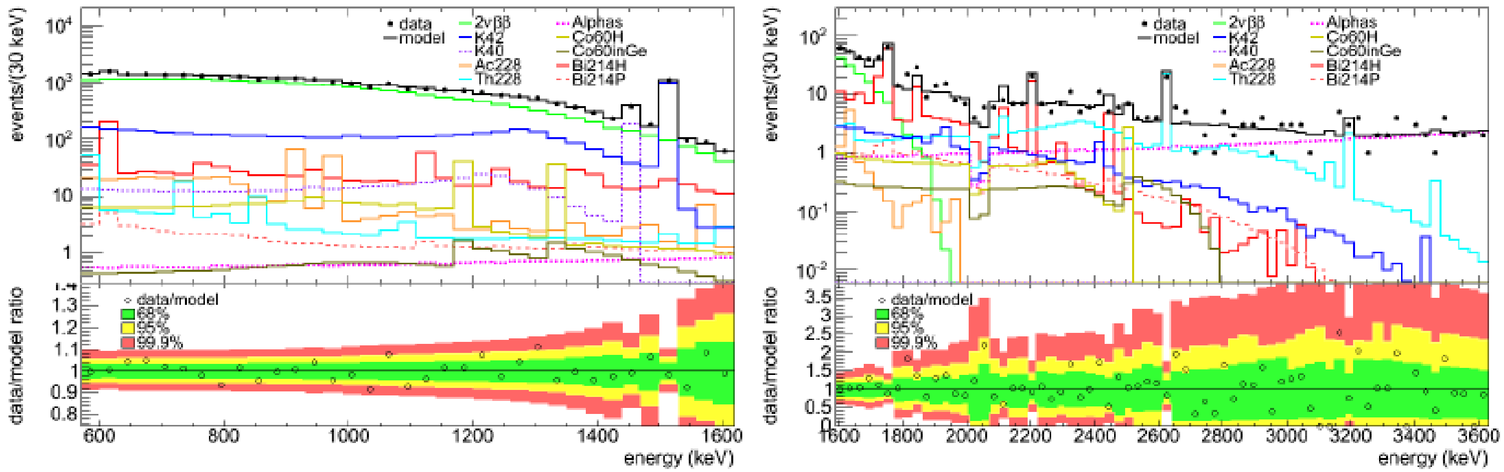
Table 6: Number of ~~fitted~~ events in the whole energy range (0 - 7.5 MeV) from each component of the alpha model obtained for different data sets. Shown are the mode and the smallest 68 % probability intervals or 90 % quantiles of the marginalized distributions of the parameters.

	GOLD-coax		*GOLD-nat*		*GOLD-hdm*		*GOLD-igex*	
	number of counts in the spectrum							
^{210}Po p$^+$	1355	[1310,1400]	76.5	[66,88]	1285.5	[1240,1320]	74.5	[65,86]
^{226}Ra p$^+$	50.5	[36.0,65.0]	27.5	[20,36]	46.5	[35,62]	8.5	[5,13]
^{222}Rn p$^+$	24.5	[18,33]	13.5	[9,20]	23.5	[17,32]	6.5	[3,10]
^{218}Po p$^+$	13.5	[9.0,19.0]	15.5	[10,20]	13.5	[9,19]		<6
^{214}Po p$^+$		<10		<11		<9		<7
^{226}Ra LAr		<159.0		<45		<148		<26
^{222}Rn LAr		<64		<25		<52		<10
^{218}Po LAr		<30		<26		<30		<6
^{214}Po LAr	19.5	[10, 29]	16.5	[8,27]	14.5	[8,25]		<5

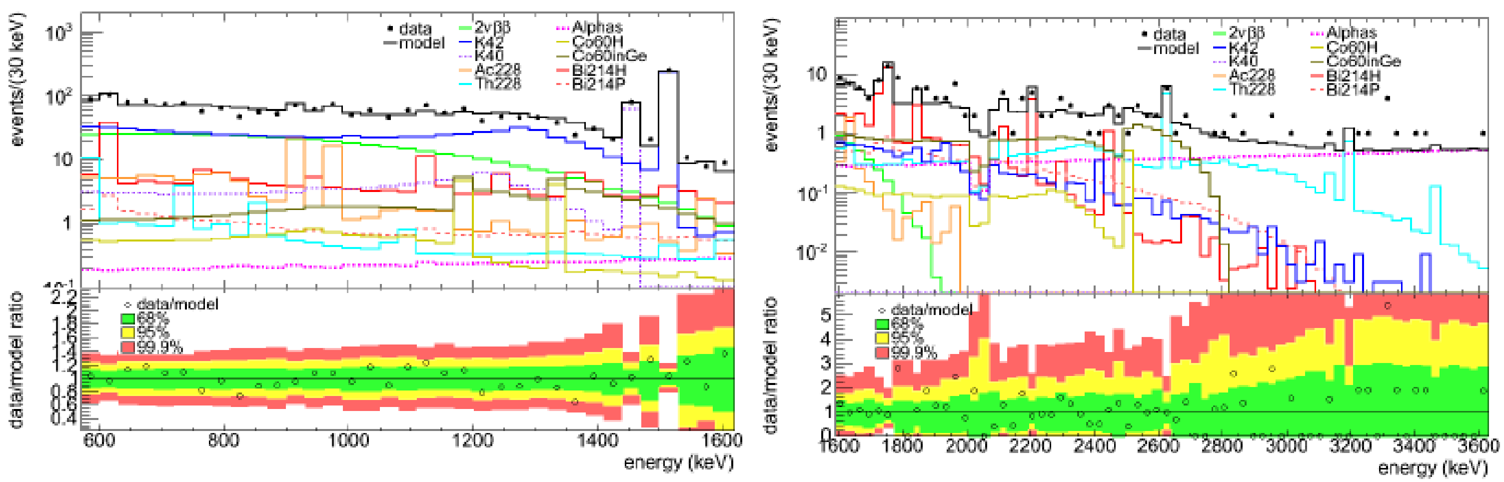
arXiv:1306.5084

Background model for coax detectors

GOLD-coax (minimum)

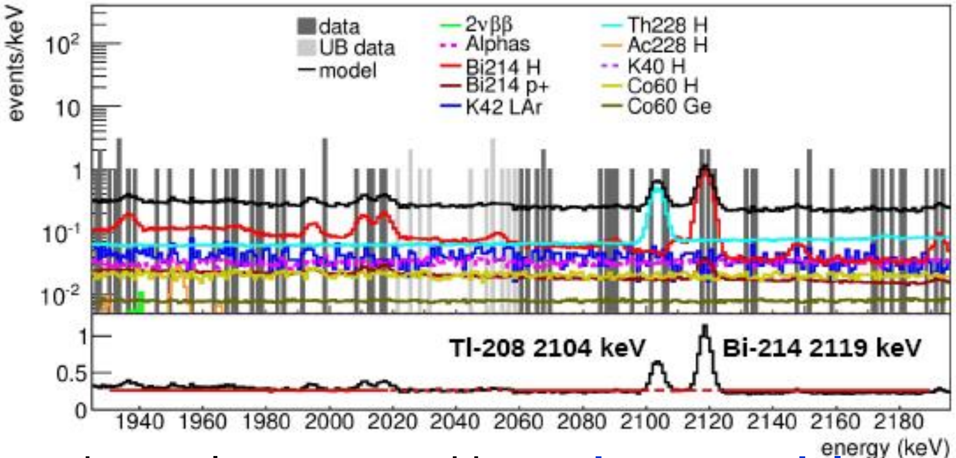


GOLD-nat (minimum)



arXiv:1306.5084

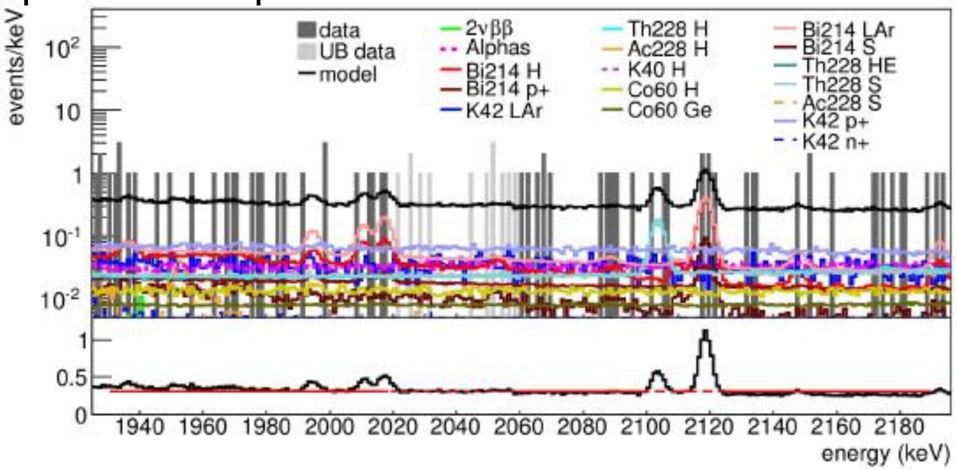
Experimental spectrum with **minimum model** around Qββ



GOLD- coax data set.

~20% p+ surface events due to alphas and Bi-214 on p+ surface

Experimental spectrum with **maximum model** around Qββ



~50% p+ surface events due to alphas, Bi-214 on p+ surface and in LAr close to p+ surface, K-42 on p+ surface

arXiv:1306.5084

The upper panels show the individual contributions of the considered background sources to the total background spectrum in logarithmic scale.

The lower panels show the best t models fitted with a constant. In the fit the peak areas predicted by the model and the 40 keV blinding window are not considered.

The light grey shaded (unblinded data - **UB data**) events in the experimental spectrum have not been used in the analysis.

Background models and BI predictions

GOLD runs: for BI models 417.4 days used,

(**SILVER** runs: for BI models 32.6 days used)

	GOLD-coax	*GOLD-nat*	*SUM-bege*
	BI in central region around $Q_{\beta\beta}$ (10 keV for coaxial, 8 keV for BEGe) 10^{-3} cts/(kg keV yr)		
interpolation	17.5 [15.1,20.1]	30.4 [23.7,38.4]	36.1 [26.4,49.3]
minimum	18.5 [17.6,19.3]	29.6 [27.1,32.7]	38.1 [37.5,38.7]
maximum	21.9 [20.7,23.8]	37.1 [32.2,39.2]	
	background counts in the previously blinded energy region		
	30 keV	40 keV	32 keV
data	13	5	2
minimum	8.6 [8.2,9.1]	3.5 [3.2,3.8]	2.2 [2.1,2.2]
maximum	10.3 [9.7,11.1]	4.2 [3.8,4.6]	

The BI interpolated into the region of interest is $(1.75^{+0.26}_{-0.24})\cdot 10^{-2}$ cts/(keV·kg·yr) for the coaxial detec-

arXiv:1306.5084

Background index predictions

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) 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		>0.1		>0.1	9.2	[4.5,12.9]	1.0	[0.3,1.0]
^{68}Ge	germanium								(<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^+			*	<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				<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				<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]

arXiv:1306.5084

Unblinding of the GERDA Phase-I 0νββ data

GERDA has unblinded the data after 1.5 years of data taking (558.6 days) on 14 June 2013 at the GERDA Collaboration Meeting in Dubna.

This happened after developing a model for the background and several methods of PSD for BEGe and semi-coaxial detectors.

The background model has been presented at the LRT conf. at LNGS in April 2013, proceedings in arXive:1306:2302. The background paper is placed at http://arxiv.org/abs/1306.5084 there procedures and predictions are published.
PSD of BEGes has been published in several papers and conf. proceedings.
PSD on semi-coaxial: the primary procedure is based on articial neural network (ANN) , two other methods confirm the results. Complete PSD paper is close to publishing.

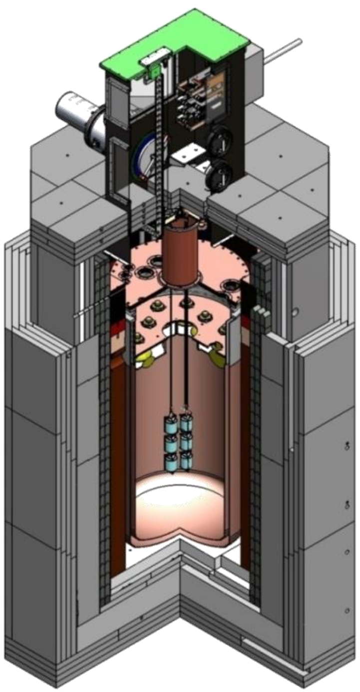
During the Meeting parameters and procedures of unblinding were finally fixed.

The **official announcement** on **0νββ Phase-I results** will be presented & published soon (*more probably – middle of July, at* a seminar at LNGS *July 14 -16 and / or at EPS-HEP conference, Stockholm, July 18 -24*).

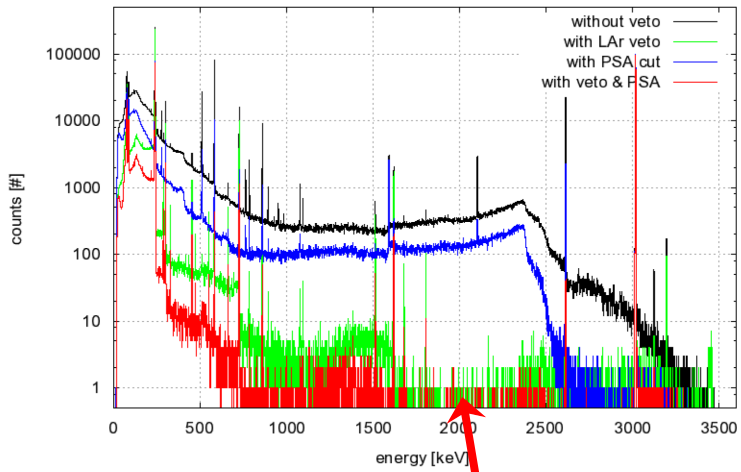
R&D for GERDA Phases II and III
LArGe test facility + BEGe detectors

The LArGe Setup with 1.4 tons of LAr

9 PMTs: 8” ETL9357;
Reflector: VM2000
& wavelength shifter;
Cryostat: ∅ 90 cm x 205 cm, volume: **1000 liter;**
Shield: Cu -15 cm, Pb -10 cm, Steel- 23 cm, PE- 20 cm.



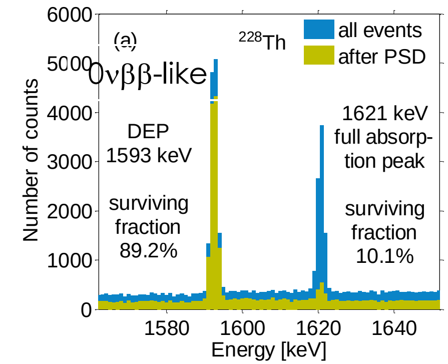
The LArGe set up was assembled at LNGS in 2010 and operates with naked Ge detectors immersed in 1.4 tons of LAr served as scintillation veto. Efficiency of the LAr scintillation veto and pulse shape discrimination (PSD) of signals from the BEGe detector inside the LArGe were tested and optimized . It was shown that the internal background from Th-228 suppressed in LArGe by factor 5000 after applying LAr veto and PSD.



ROI – reduction factor > **5000**

First naked BEGe inside LArGe

BEGe parameters in LArGe:
High voltage 4000 V
Leakage current ~ 4 pA
FWHM @ 1.33 MeV 1.8 keV
mass 878 g



First results obtained with LArGe + BEGe successfully demonstrate possibility of considerable background reduction for GERDA Phase II and III by using LAr scintillation veto + BeGe PSD.

Phase II: LAr Scintillation Veto

- Experimental prove of principle

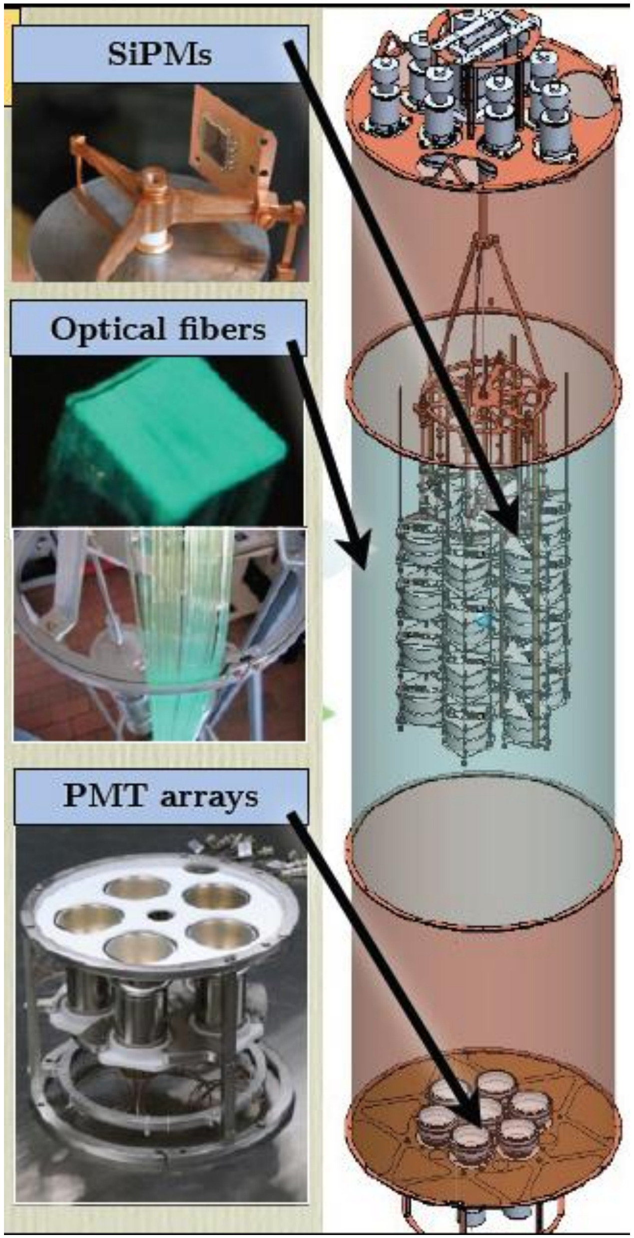
in R&D facility **LArGe** (LNGS)

- Investigation of different design principles

for GERDA with tuned MC simulations:

- **PMT arrays** on top and bottom
- **Fiber shroud** with SiPM readout
- **SiPMs** inside mini shroud (if deployed)

- **Combination of designs is favored**



Conclusions and Outlook

1. GERDA finished Phase I data taking on May 21, 2013.

Background around Q **order of magnitude lower** than previous experiments **0.020 - 0.015** cts/(keV kg yr),

Corresponding average expected **0νββ** sensitivity of:

$$T_{1/2}^{0\nu} \gtrsim 1.9 \cdot 10^{25}\,\mathrm{yr}$$

2. **9 November 2011 – 21 May 2013:**

558.6 days of data taking,

-> exposure:

Enriched Ge-76 detectors: **21.612 kg*yr,**
Natural Ge detectors: **6.192 kg*yr**

3. **Unblinding** has been done on 14 June 2013 at the GERDA Collaboration Meeting in Dubna. Complete Phase-I results will be presented & published soon (*more probably – at* a seminar at LNGS *July 14 -16 and / or at EPS-HEP conference, Stockholm, July 18 -24*).

4. Measured 2νββ half-life with a strong reduction of systematic uncertainties with respect to the previous experiments

$$T_{1/2}^{2\nu} = (1.84^{+0.09}_{-0.08}\ _{\text{fit}}\ {}^{+0.11}_{-0.06}\ _{\text{syst}}) \cdot 10^{21}$$

5. More precise 2νββ analysis by using all Phase I data will be done.

6. **Phase II preparation** ongoing and hardware integration

will start from September 2013.

Major upgrade for further reduction of the background

to the level of **0.001 cts/(keV kg yr)**

(Pulse shape analysis with BEGe detectors and LAr instrumentation).

Thanks for your attention!

And hope to see you
at the next NANPino

Extra slides

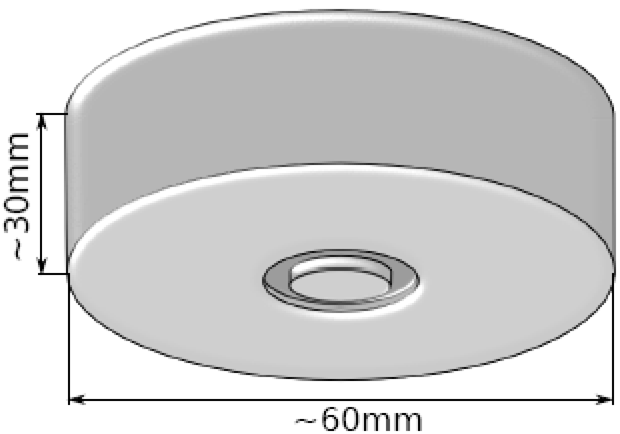
Activity of sources due to background model

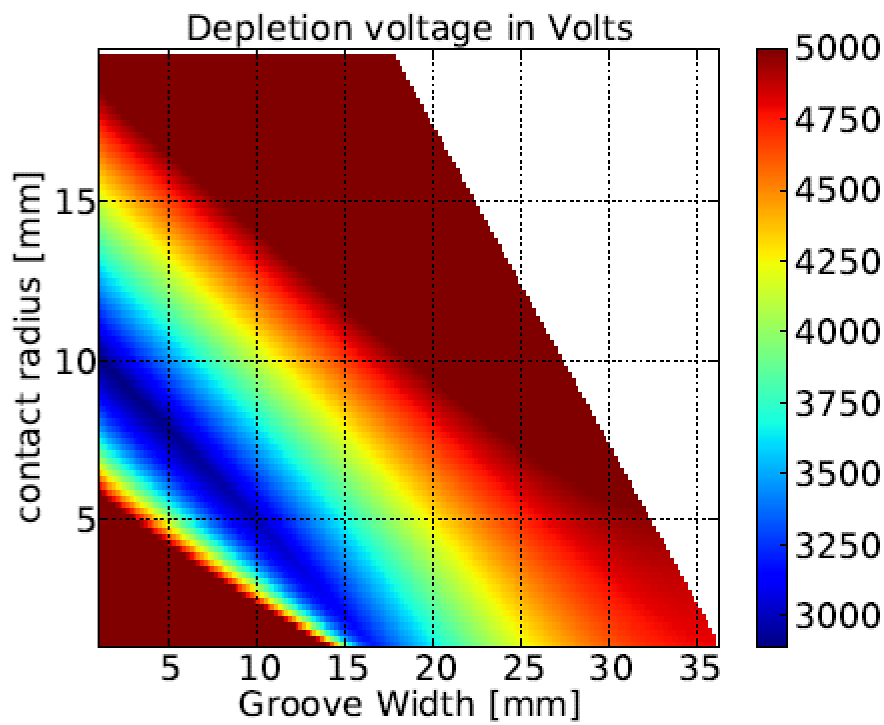
Table 7: Activities of the individual contaminations of different hardware components derived from the global models of different data sets. The location of the sources is also indicated: cl. - close source, med. medium distance source, far - distant source. The numbers are according to the best fit model. The uncertainty interval (upper/lower limit) obtained as the smallest 68 % interval (90%/10% quantile) of the marginalized distributions of the parameters are given as well. Also the activities as derived from the coincident spectra (see sec. 7) are shown.

source - location		units	*GOLD-coax* minimum	*GOLD-coax* maximum	*GOLD-nat* minimum	*GOLD-coax* coincident
^{40}K - cl.	det. assembly	µBq/det.	152[136,174]	151[136,174]	218[188,259]	252[164,340]
^{42}K - cl.	LAr	µBq/kg	106[103,111]	91[72,99]	98.3[92,108]	168[150,186]
^{42}K - cl.	p^+ surface	µBq		11.6[3.1,18,3]		
^{42}K - cl.	n^+ surface	µBq		4.1[1,2,8.5]		
^{60}Co - cl.	det. assembly	µBq/det.	4.9[3.1,7.3]	3.2[1.6,5.6]	2.6[0,6.0]	5.0[2.5,7.5] *)
^{60}Co - cl.	germanium	µBq	>0.4 †)	>0.2 †)	6[3.0,8.4]	
^{214}Bi - cl.	det. assembly	µBq/det.	35[31,39]	15[3.7,21.1]	34.1[27.3,42.1]	40[28,52]
^{214}Bi - cl.	LAr close to p^+	µBq/kg		* <299.5		
^{214}Bi - med.	radon shroud	mBq		<49.9		
^{214}Bi - cl.	p^+ surface	µBq	2.9[2.3,3.9]	3.0[2.1,4.0] †)	1.6[1.2,2.1] †)	
^{228}Th - cl.	det. assembly	µBq/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}Ac - cl.	det. assembly	µBq/det.	17.8[10.0,26.8]	<15.7	25.9[16.7,36.7]	33[18,48]
^{228}Th - med.	radon shroud	mBq		<10.1		
^{228}Ac - med.	radon shroud	mBq		91.5[27,97]		
^{228}Th - far	heat exchanger	Bq		<4.1		

Possible Detector optimization for further GERDA phases:

- For a crystal slice many fixed parameters: Impurity gradient, height, radius
- There are a few free parameters: size of point contact, groove width
- Depletion voltage as a function of the free parameters
- A compromise between values of free parameter and depletion voltage can be found



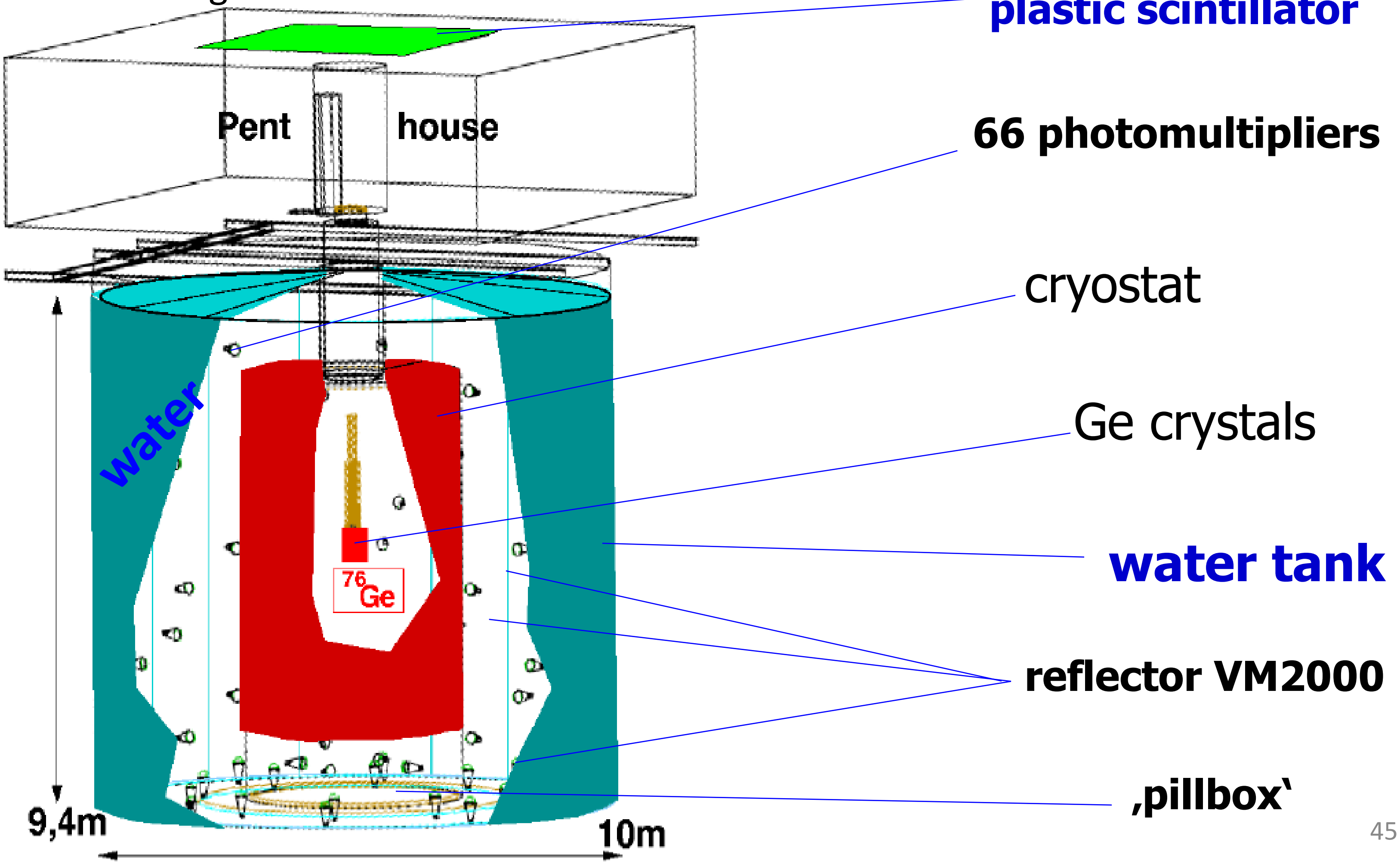


See: M.Salathe, DPG-Frühjahrstagung, Dresden, March 4, 2013

Water tank and Veto system

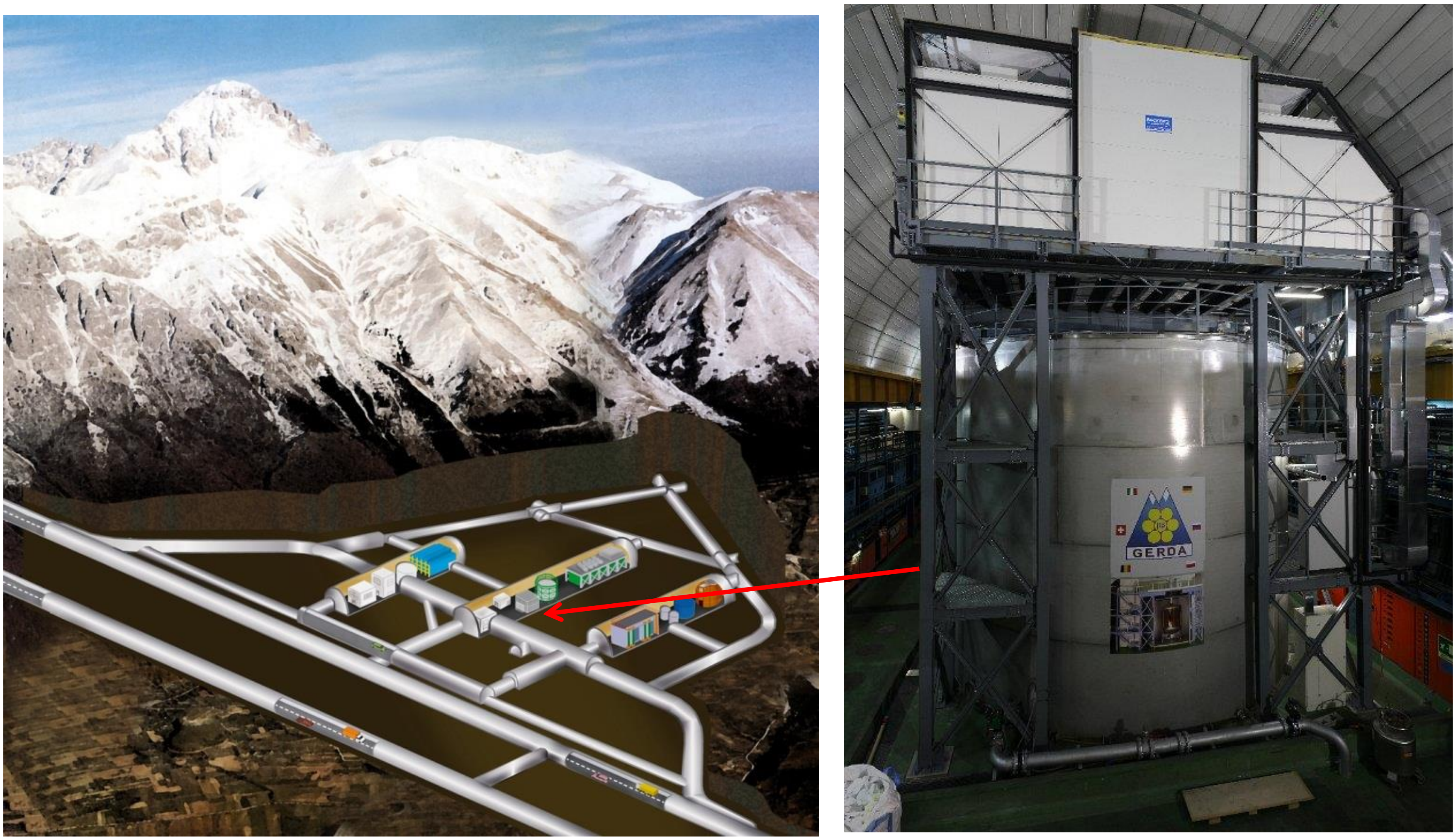
The ultra-pure water buffer serves as **a gamma and neutron shield** and, instrumented with 66 photomultipliers, as Cherenkov detector **for efficiently vetoing** cosmic muons.

Plastic scintillator panels on top of the detector will tag muons which enter the dewar through the neck.

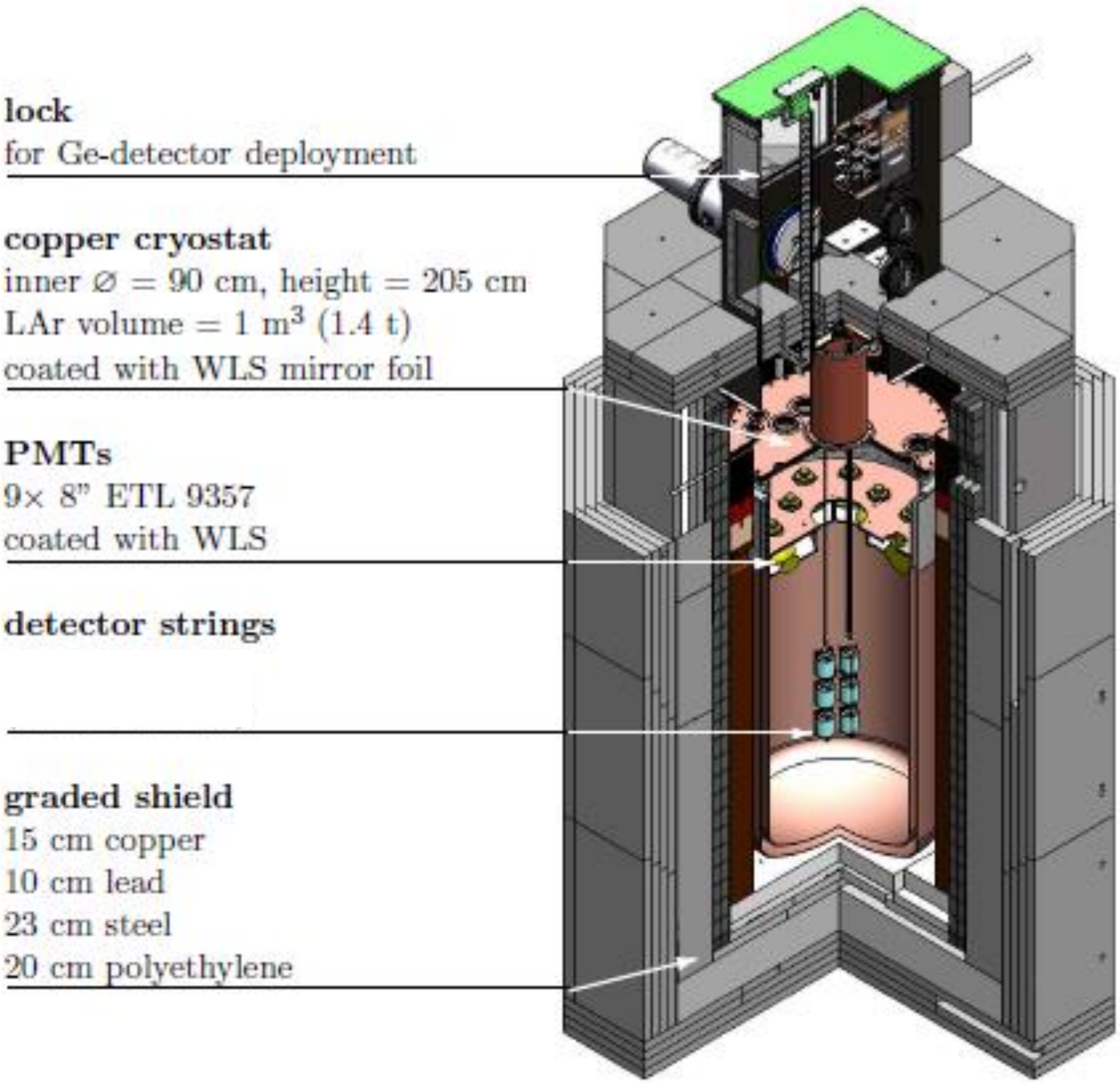


Background reduction

GERDA experiment located at LNGS underground laboratory (Italy). The rock overburden is equivalent to 3400 m.w.e. This allows to reduce μ (~ 10^6 times) and neutron flux.



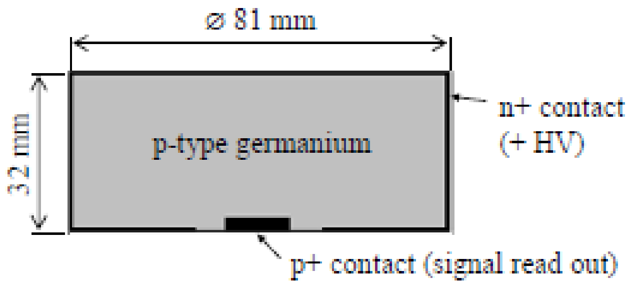
LArGe -R&D liquid argon scintillation

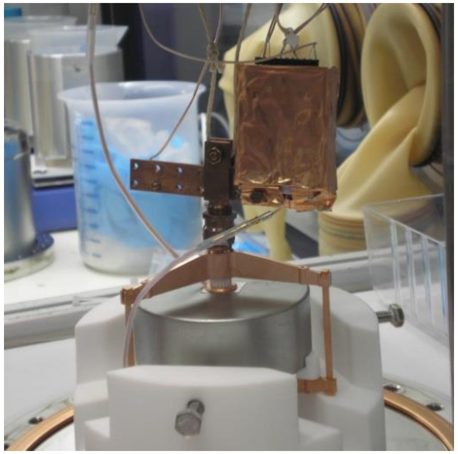


Low background **GERDA-LArGe test facility** @ LNGS: Detection of coincident liquid argon scintillation light to discriminate background

First Naked BeGe detector inside LArGe

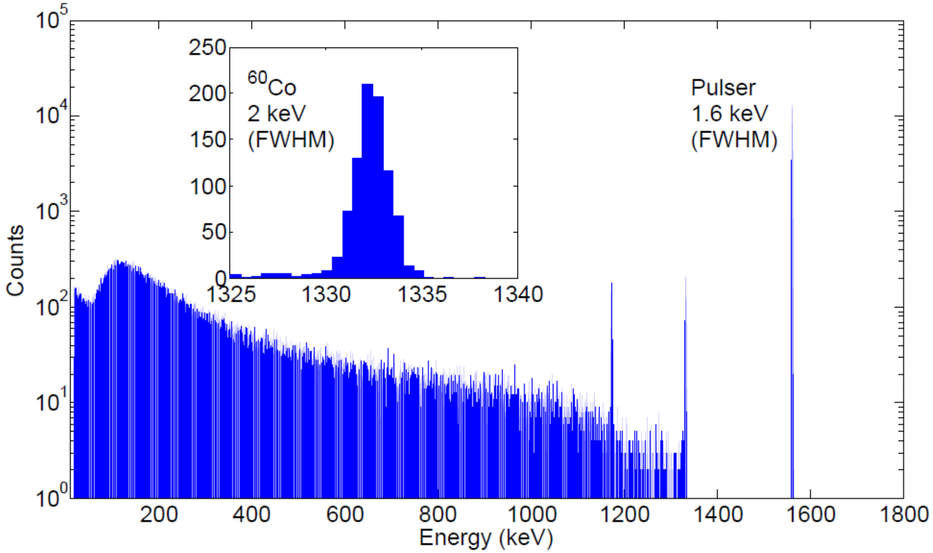
Modified model BE5030 from Canberra Semiconductor, N.V. Olen





Specifications from Canberra:

depletion voltage	4000 V
FWHM @ 122 keV	0.63 keV
FWHM @ 1.33 MeV	1.8 keV
mass	870 g



Working Parameters in LArGe:

High voltage	**4000 V**
LC	**~ 4 pA**
FWHM with pulser	**1.6 keV**
FWHM @ 1.33 MeV	**2.0 keV**
mass	**878 g**