Universität
Zürich UZH

GERDA

First results on the neutrinoless double beta decay from GERDA

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Invisibles workshop
Durham, July 17, 2013
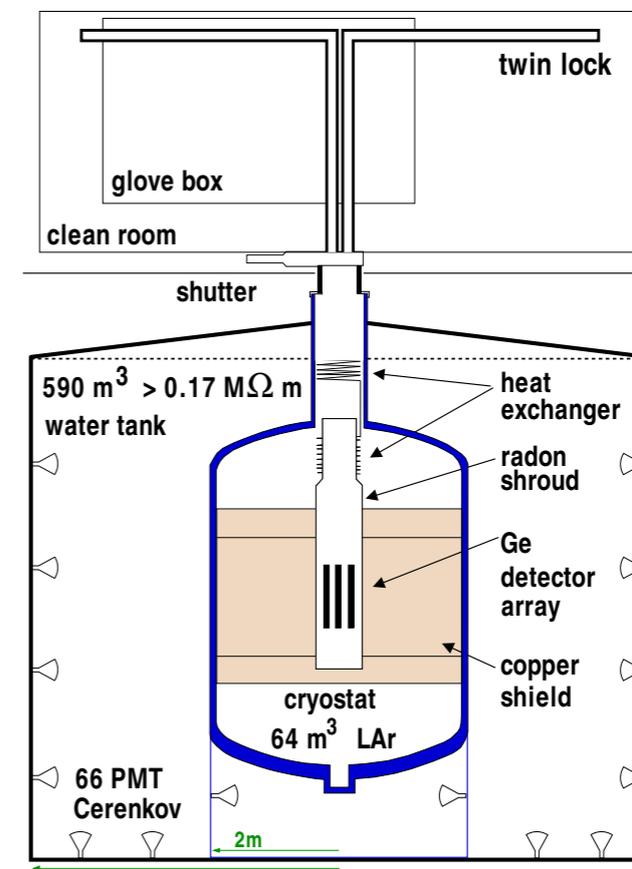
The physics

- Detect the neutrinoless double beta decay in ^{76}Ge

- Information on the nature of neutrinos and on the effective Majorana neutrino mass

$$\Gamma^{0\nu} = \frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q,Z)|M^{0\nu}|^2 \frac{|m_{\beta\beta}|^2}{m_e^2}$$

current sensitivities
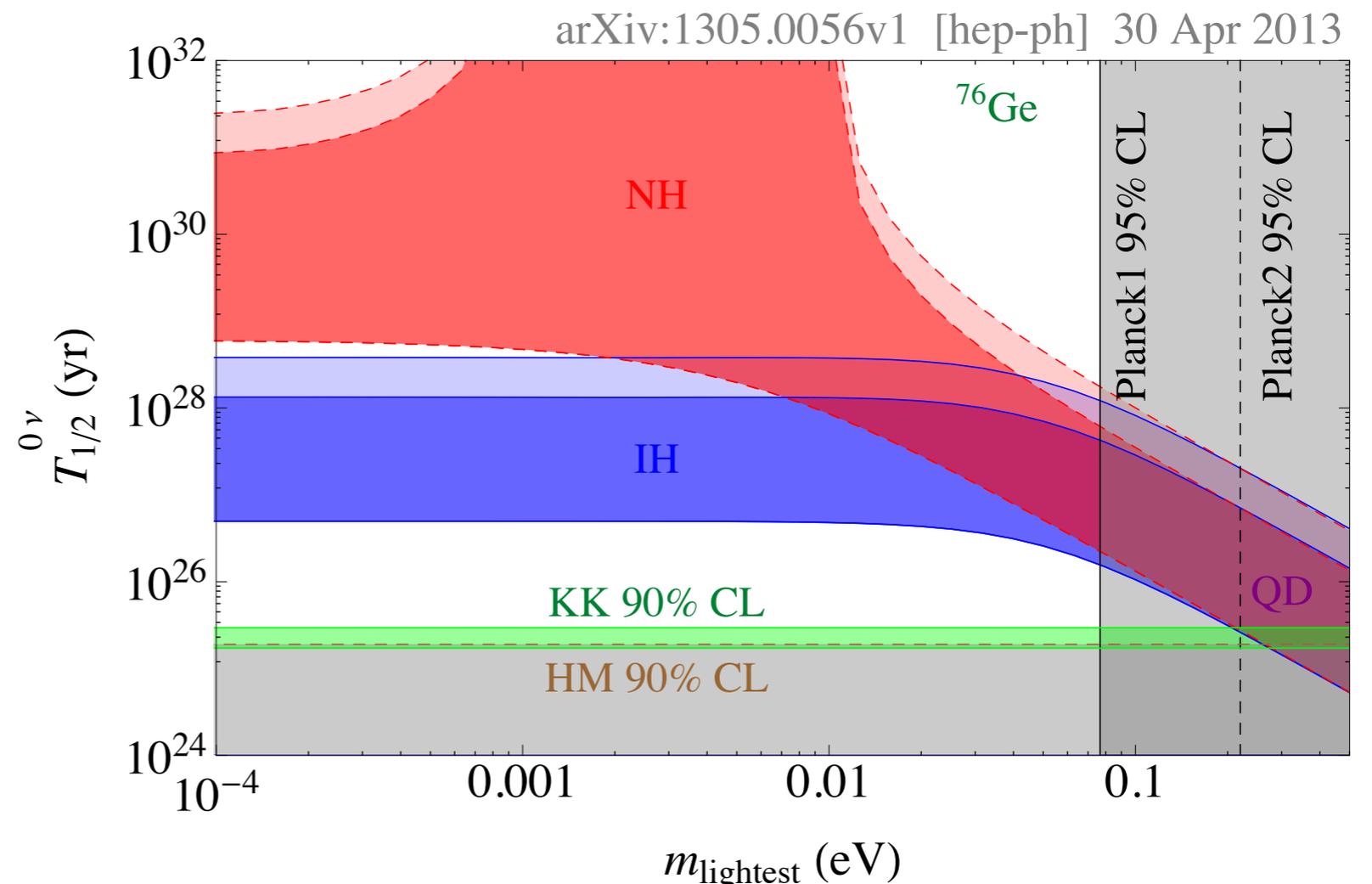
Experimental requirements

- Experiments measure the half life of the decay, $T_{1/2}$

$$T_{1/2}^{0\nu} \propto a \cdot \epsilon \cdot \sqrt{\frac{M \cdot t}{B \cdot \Delta E}}$$

$$\langle m_{\beta\beta} \rangle \propto \frac{1}{\sqrt{T_{1/2}^{0\nu}}}$$
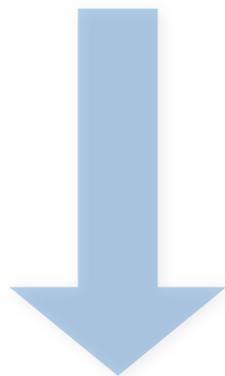
Minimal requirements:

large detector masses (M)
enriched materials (a)
ultra-low background noise (B)
*excellent energy resolution (ΔE)*
high detection efficiency

Additional tools to distinguish signal from background:

angular distribution
identification of daughter nucleus
...

The GERDA experiment at LNGS

- **Ge detectors directly submersed in LAr**

➡ LAr as cooling medium and shielding (U/Th in LAr < 7×10^{-4} µBq/kg)

➡ a minimal amount of surrounding materials

- **Phase I**

➡ 18 kg HdM and IGEX detectors

- **Phase II**

➡ additional 20 kg BEGe detectors

The GERDA collaboration

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

INR Moscow

ITEP Moscow

Kurchatov Institute

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

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JOINT INSTITUTE FOR NUCLEAR RESEARCH

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INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI MILANO

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GERDA

16 institutions
~100 members

# Collaboration meeting in Dubna, June 2013

GERDA detectors

- Phase I: p-type closed-end coaxial

- Phase II: p-type, BEGe (broad energy germanium)

- n^+ conductive Li layer, separated by a groove from the boron implanted p^+ contact

- Signal structure allows to distinguish between *single site events (SSE)* = signal-like and *multiple site events (MSE)* = background-like
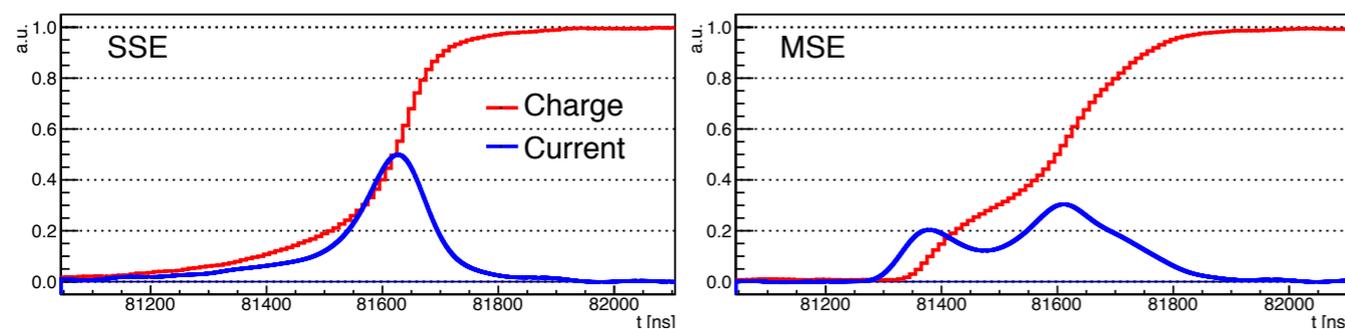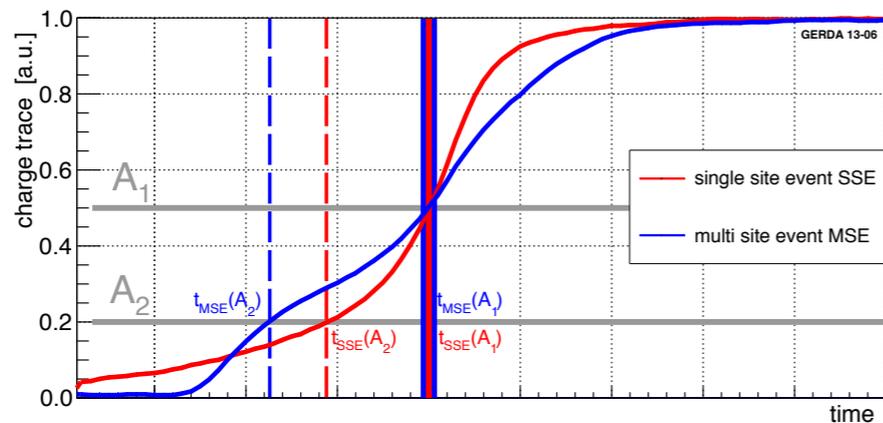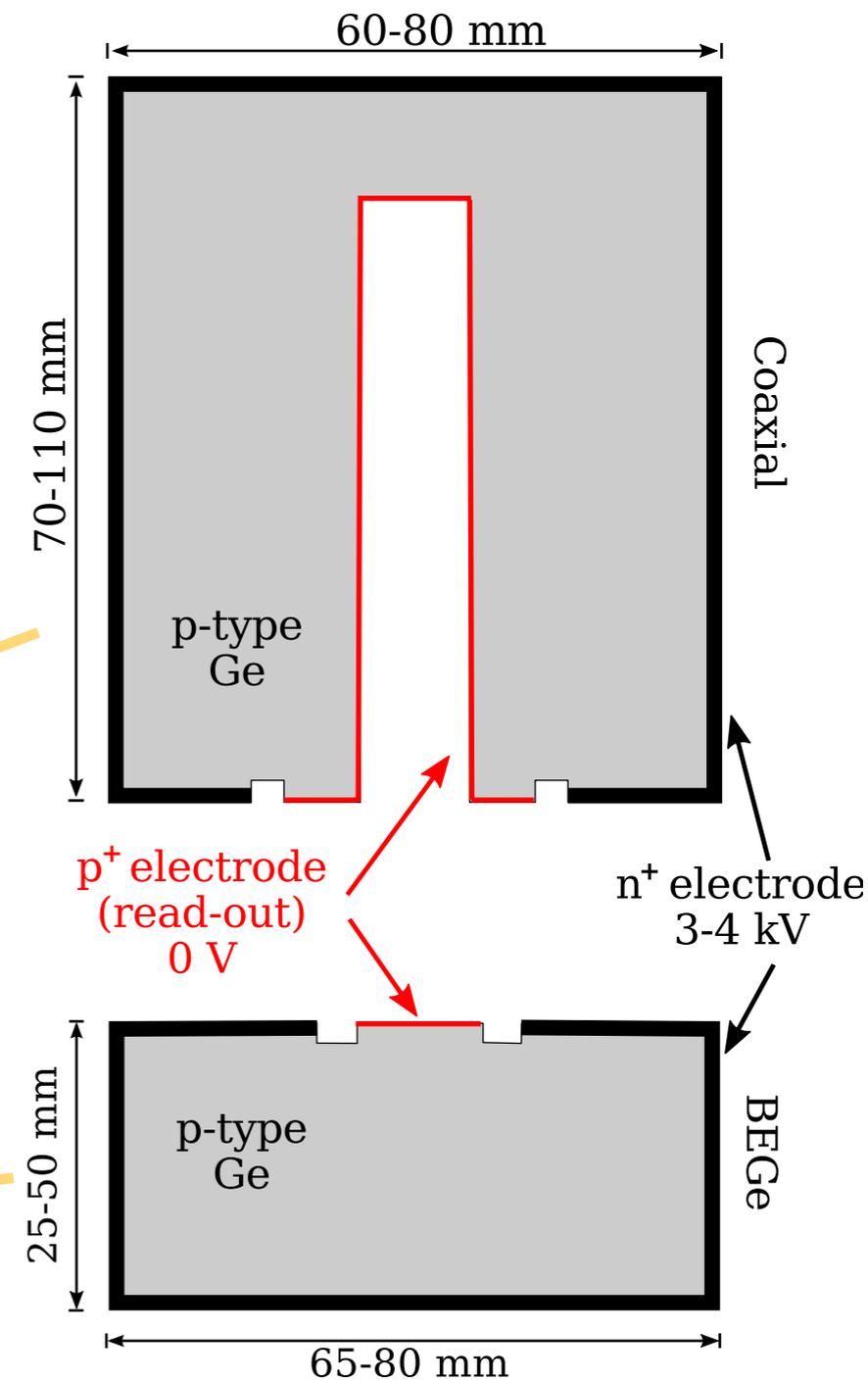
GERDA detectors

- From HdM and IGEX experiments: total mass = 17.66 kg
  - ➡ HdM: ANG1, ANG2, ANG3, ANG4, ANG5
  - ➡ IGEX: RG1, RG2, RG3
- Isotopically enriched in ^{76}Ge: 86%
- Two enriched detectors turned off because of high leakage current => 14

In addition, na   Ge detectors from Genius-TF

And 5 phase I   ched BEGe detectors added in July 2012
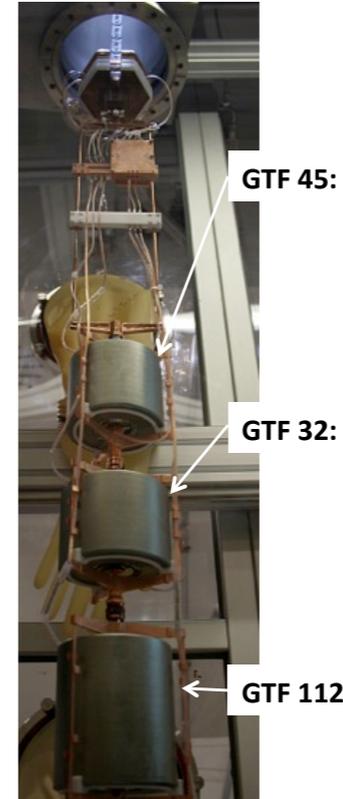
Total exposure phase I: 21.6 kg·yr

runs 25-32,34-43,44-46   GERDA 13-05

0νββ analysis

this analysis
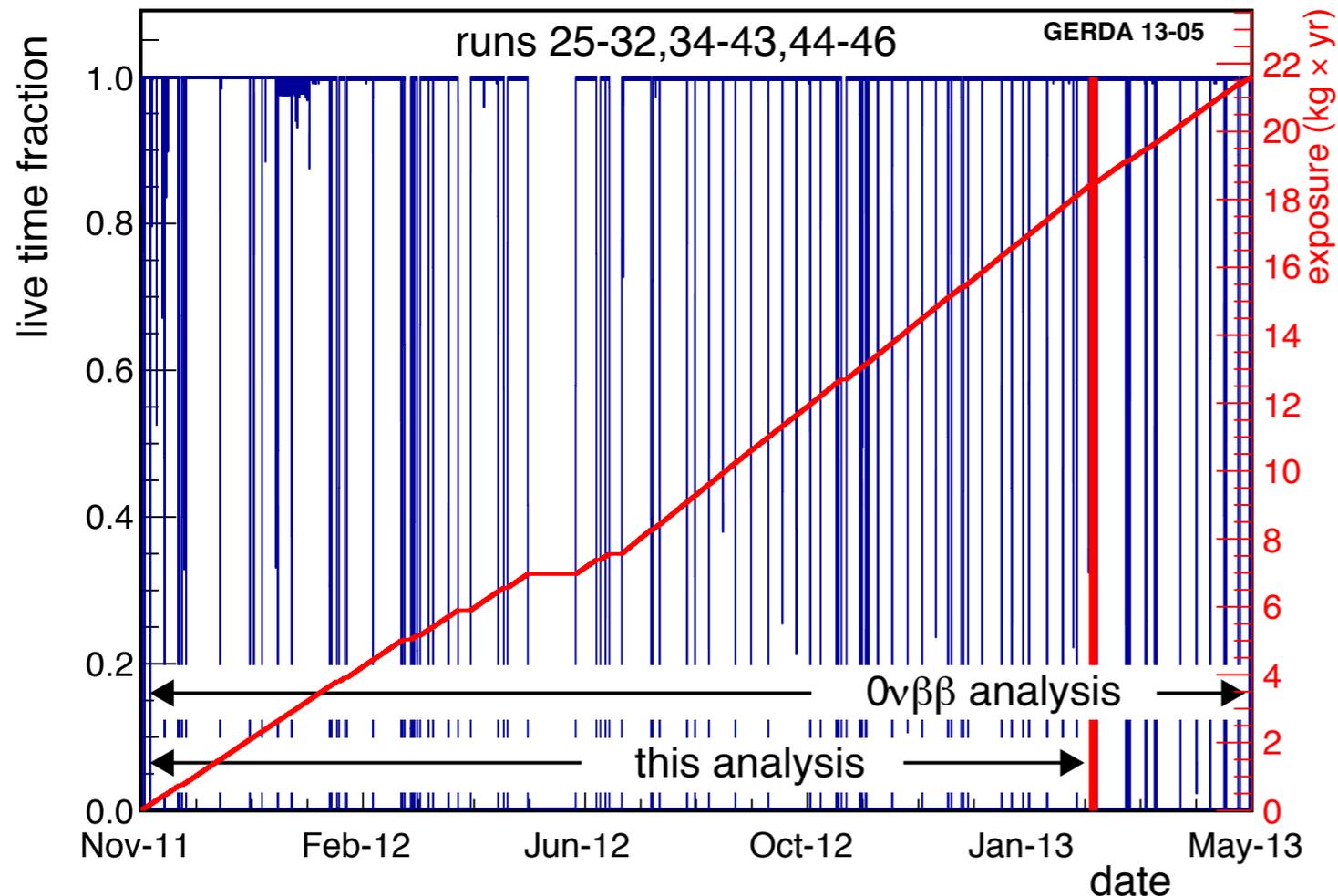
- Blue 'spikes': (bi) weekly calibrations runs with 3 ^{228}Th sources

- **Data in signal region was kept blind: Q ± 20 keV**

Cutout because of background line

ΔE

Blinded Window

E (keV)

Background analysis window
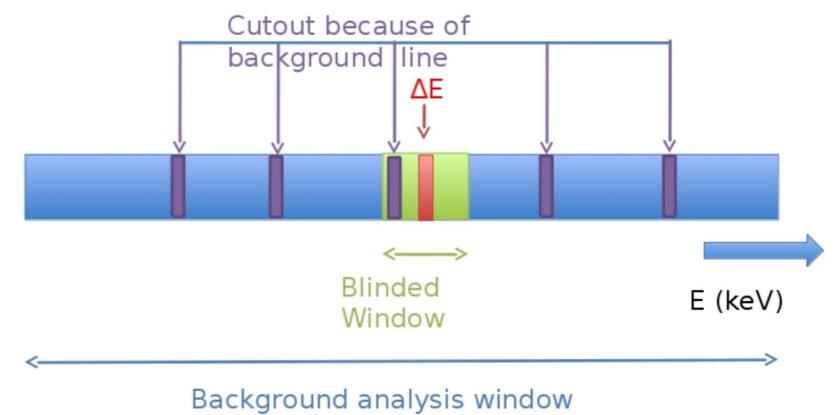
Half life of the 2-neutrino decay mode
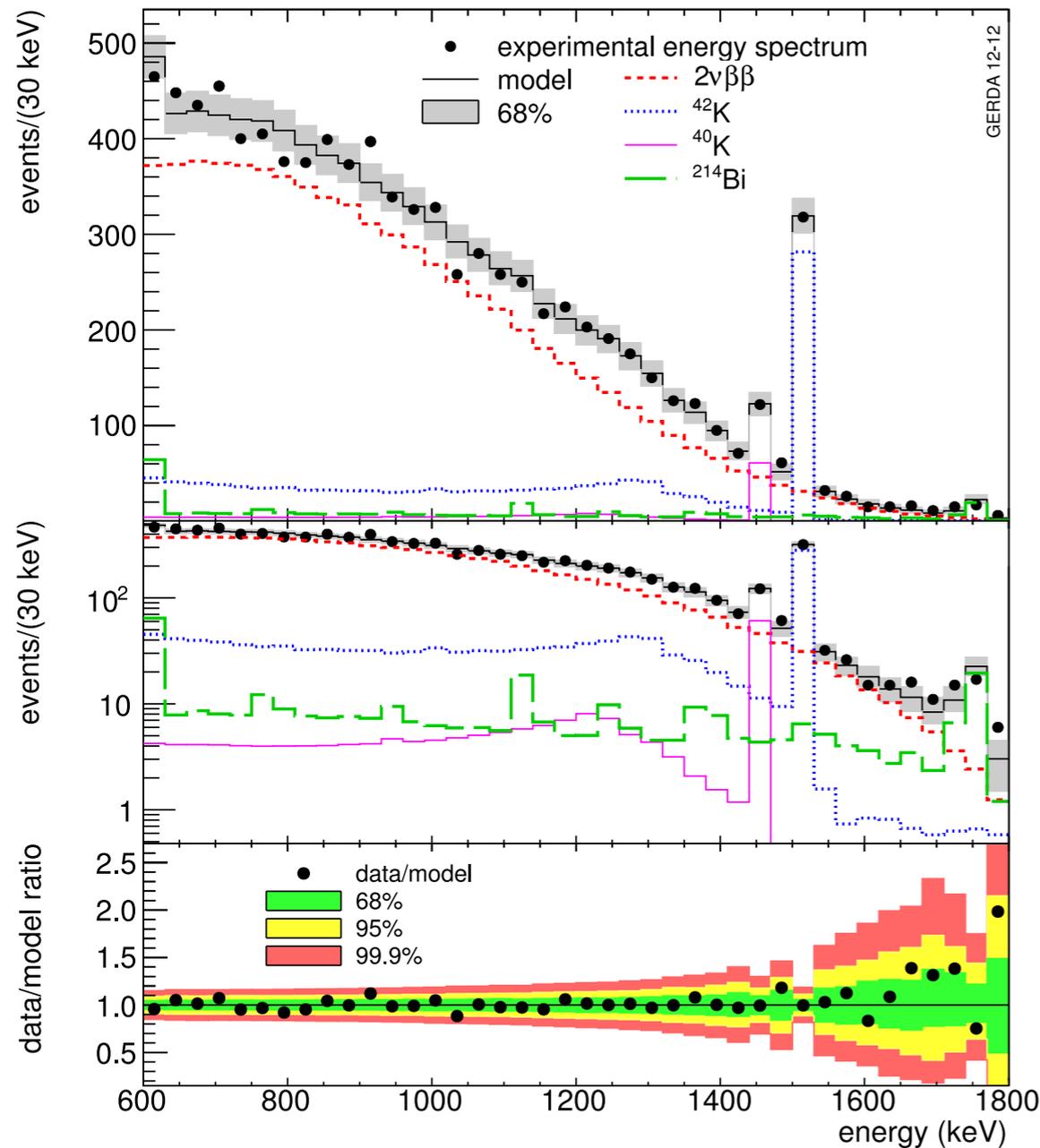
Measurement of the half-life of the two-neutrino double beta decay of ^{76}Ge with the GERDA experiment

$$T^{2\nu}_{1/2} = \left(1.84^{+0.09}_{-0.08}\right) \times 10^{21} \text{ yr}$$

Item	Uncertainty on $T^{2\nu}_{1/2}$ (%)
Non-identified background components	+5.3
Energy spectra from ^{42}K, ^{40}K and ^{214}Bi	±2.1
Shape of the $2\nu\beta\beta$ decay spectrum	±1
Subtotal fit model	+5.8 / −2.3
Precision of the Monte Carlo geometry model	±1
Accuracy of the Monte Carlo tracking	±2
Subtotal Monte Carlo	±2.2
Data acquisition and selection	±0.5
Grand total	+6.2 / −3.3

GERDA Calibration

- Determine energy resolution and stability in time
- Energy resolution: ~ 4.5 - 5 keV (FWHM) at 2.6 MeV
- Mean energy resolution at Q=2039 keV: 4.8 keV and 3.2 keV for coaxial and BEGe (FWHM)
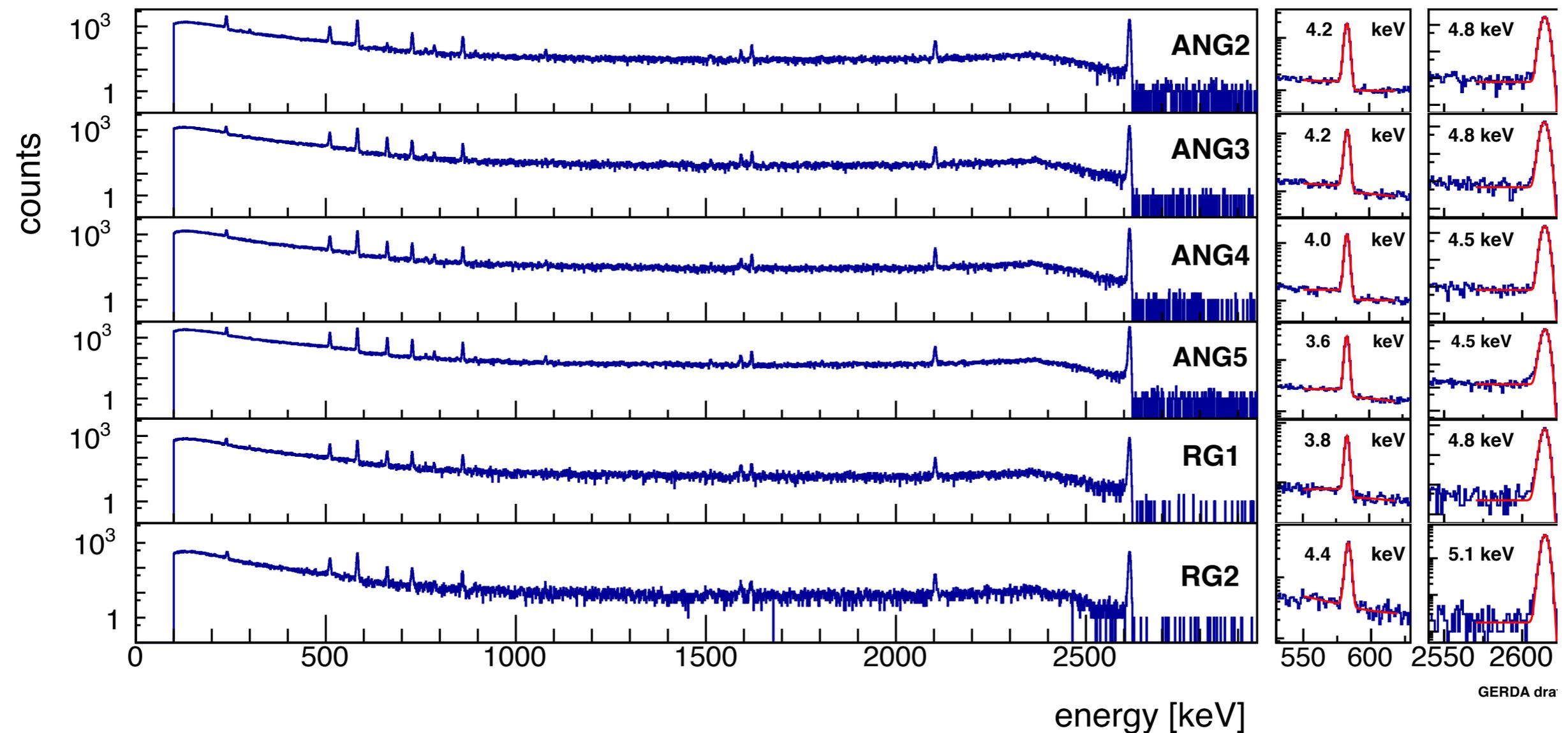
# Calibration stability

- Mean energy resolution at Q=2039 keV: 4.8 keV and 3.2 keV for coaxial and BEGe (FWHM)

^{42}K background line

all coaxial detectors

FWHM:
4.47±0.12 keV

all BEGe detectors

FWHM:
3.06±0.31 keV
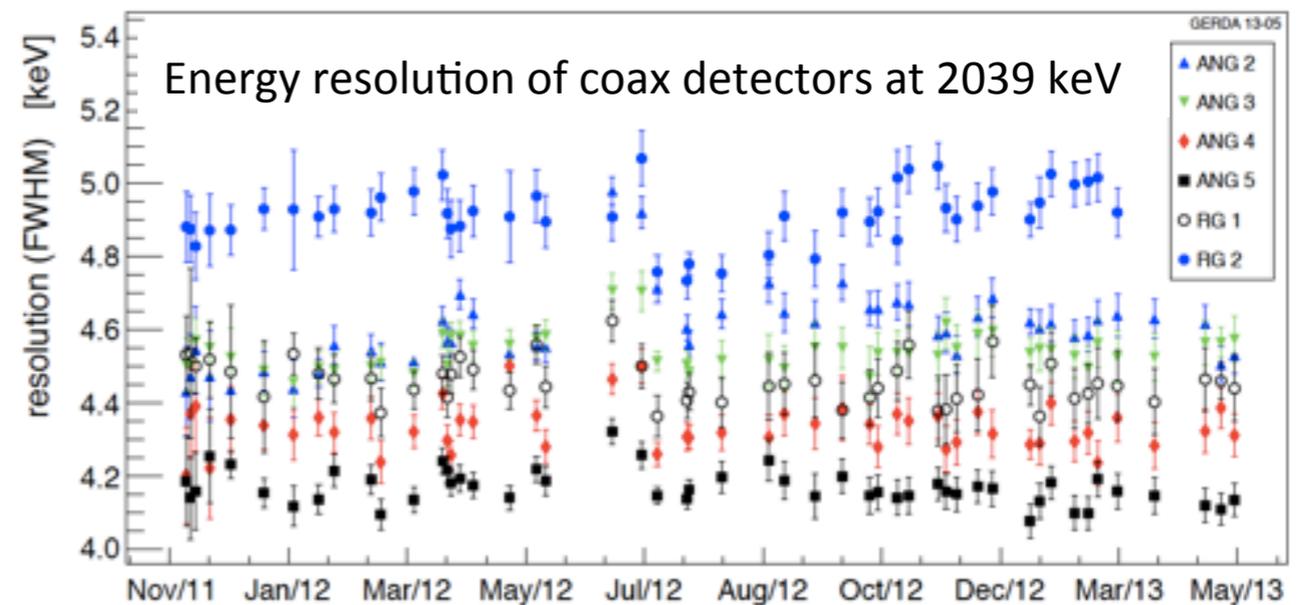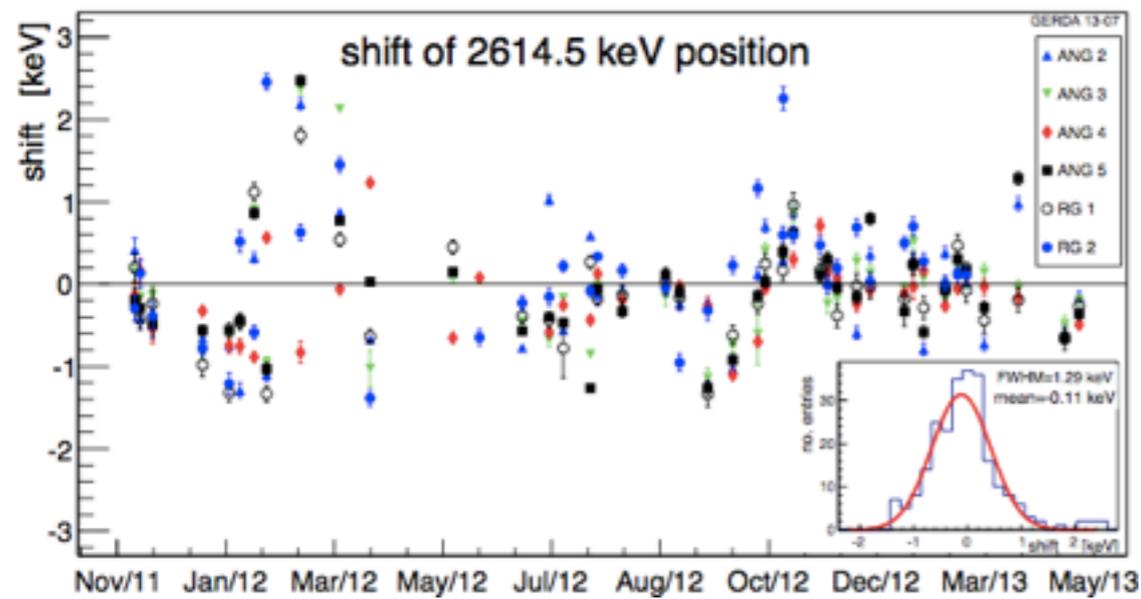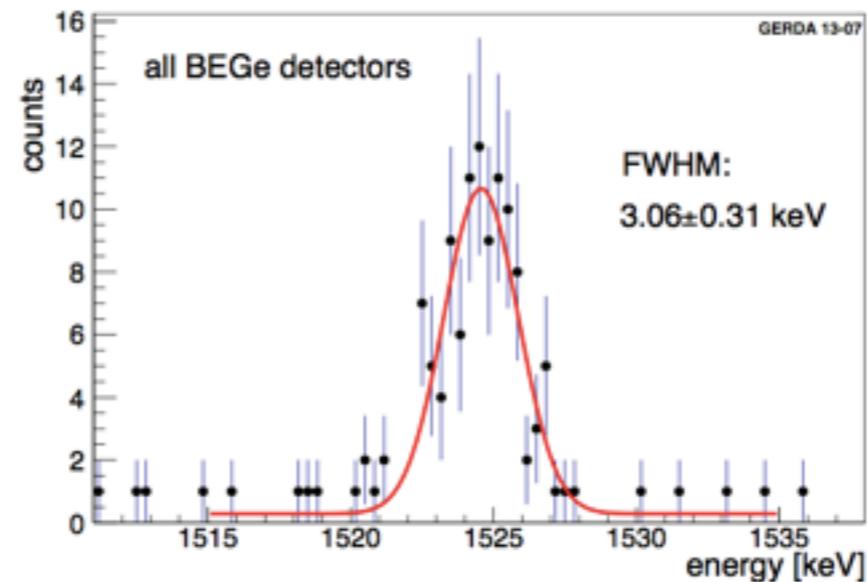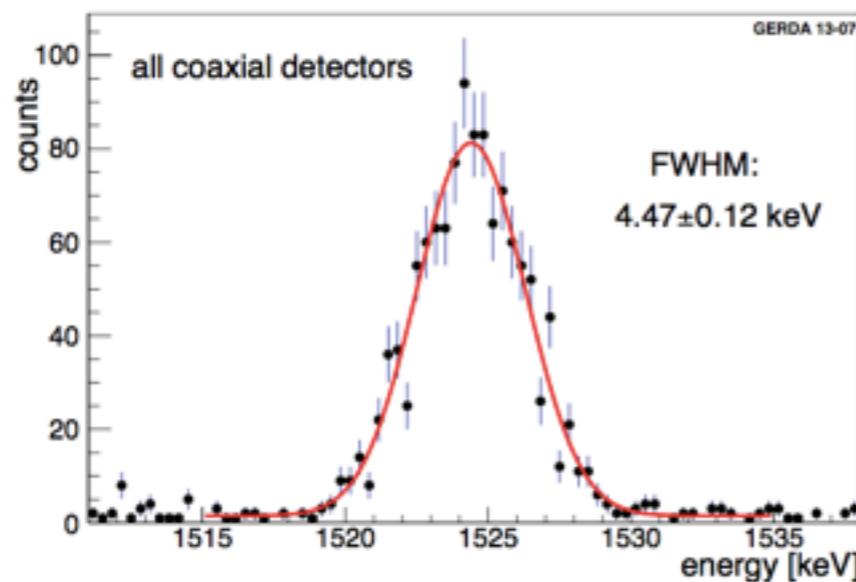
Backgrounds

arXiv:1306.5084v1 [physics.ins-det] 21 Jun 2013
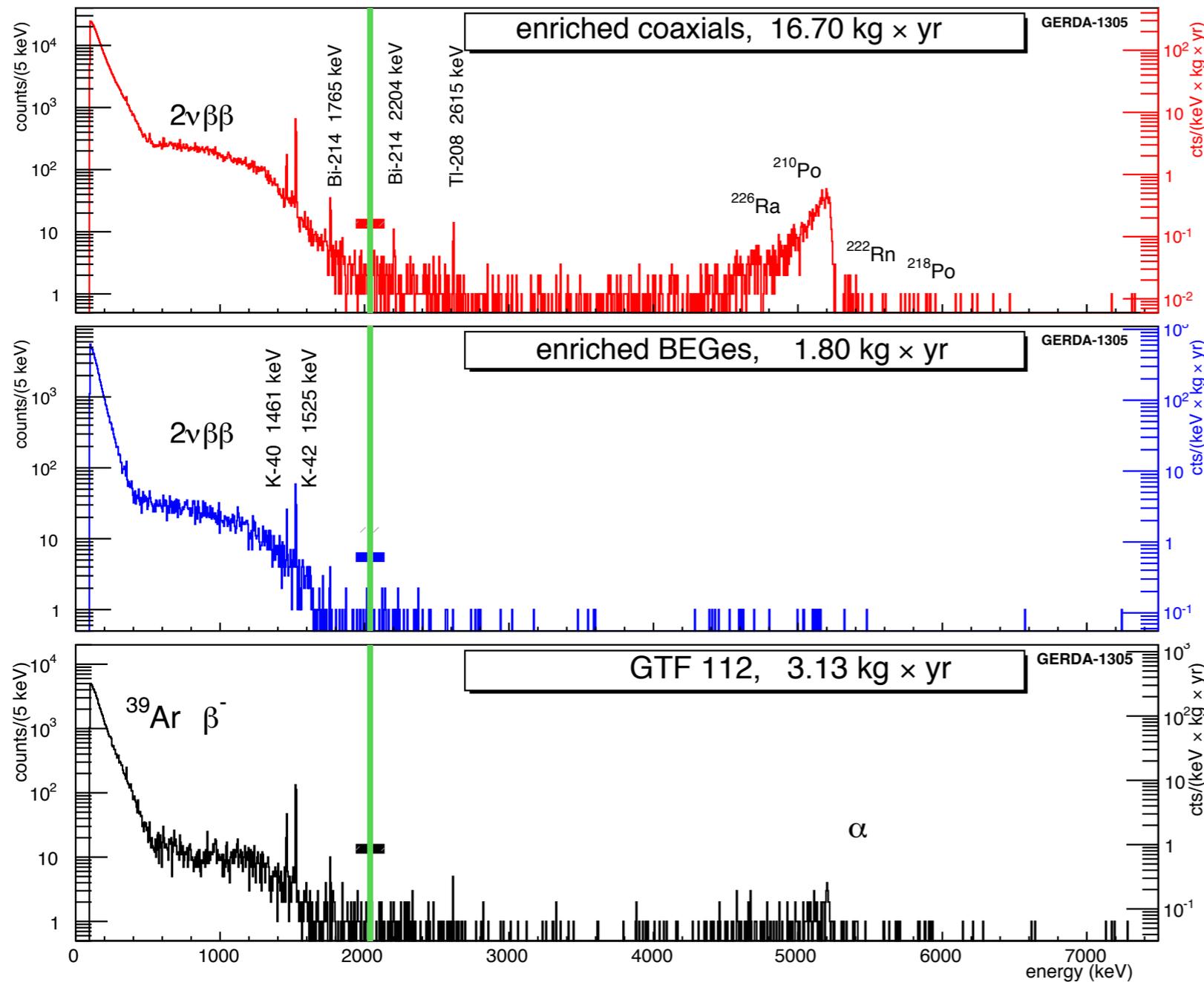
- main sources considered in the background model

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 LAr close to p^+ surface
^{208}Tl and ^{212}Bi	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

Three data sets

- The BEGe set; the coaxial data, which is split into gold and silver
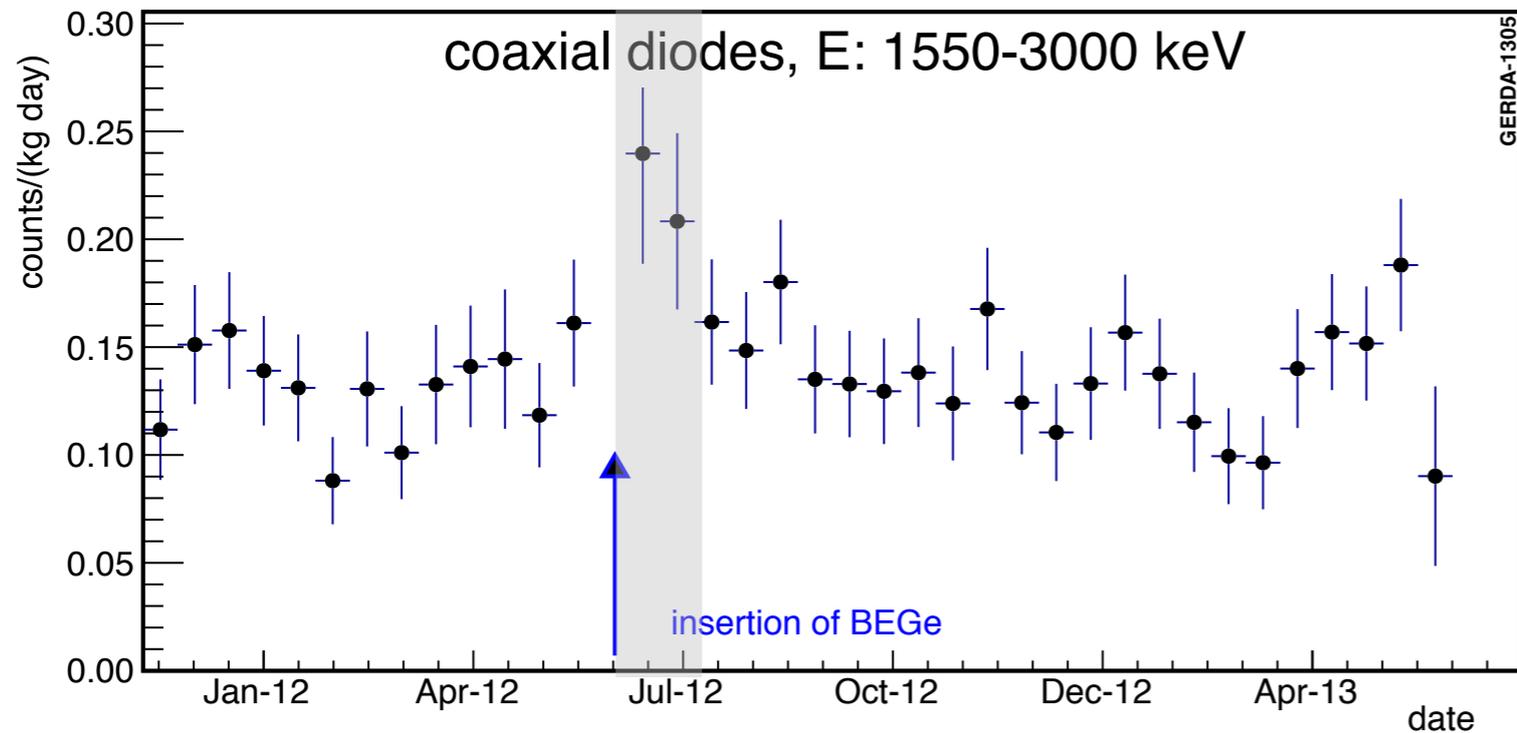
Background rate in the coaxial ^{76}Ge detectors versus time

data set	detectors	exposure $\mathcal{E}$	
		this analysis	$0\nu\beta\beta$ analysis
		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

The background model

Fig. 12 Background decomposition according to the best fit minimum model of the *GOLD-coax* data set. The lower panel in the plots shows the ratio between the data and the prediction of the best fit model together with the smallest intervals of 68 % (green band), 95 % (yellow band) and 99.9 % (red band) probability for the ratio assuming the best fit parameters.
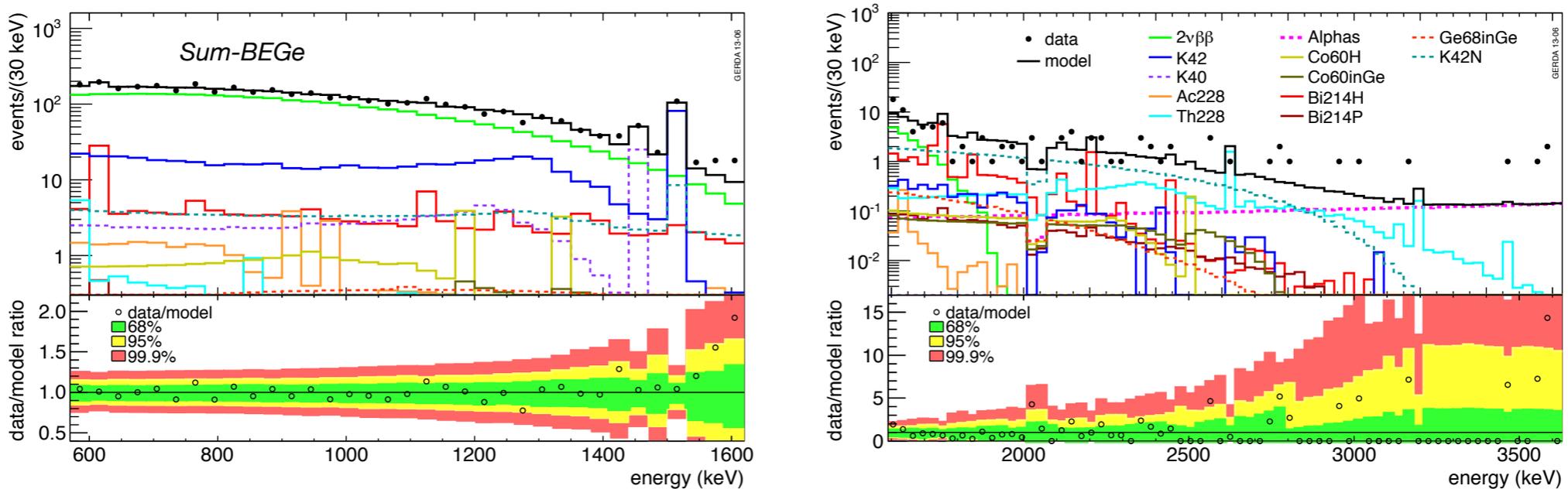
Background in the ROI for the double beta decay

- Consistent with a flat background in the energy region: 1930 keV - 2190 keV
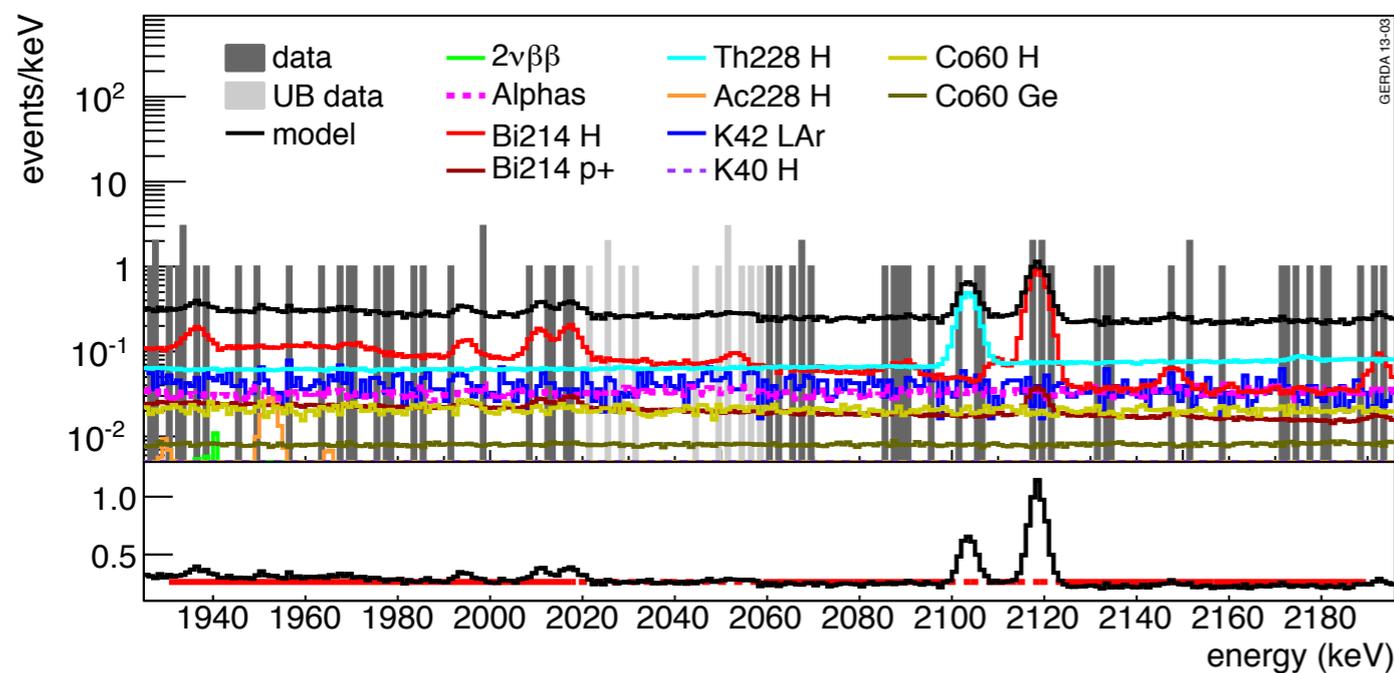
The background level interpolated into the region of interest is:

Coaxial:

$$\left(1.75^{+0.26}_{-0.24}\right) \cdot 10^{-2} \text{ events}/(\text{keV kg yr})$$

BEGe

$$\left(3.6^{+1.3}_{-1.0}\right) \cdot 10^{-2} \text{ events}/(\text{keV kg yr})$$
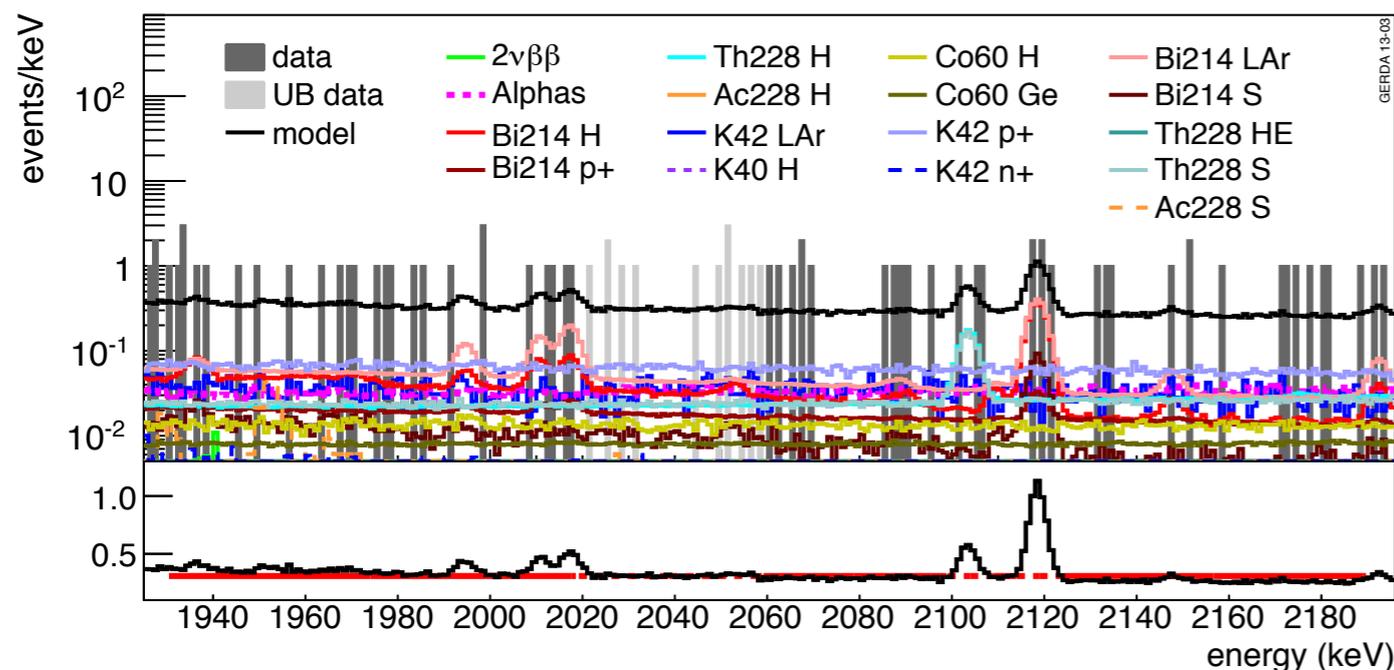
Linear fit with flat background in 1930 keV - 2190 keV, excluding peaks at 2104 keV and 2119 keV

Pulse shape discrimination

- BEGes: simple *A/E-parameter* cut
  - ➡ rejects 80% of background events
  - ➡ keeps 92% of signal-like events

- Coaxial Ge: *neural network analysis* (cross checked by two additional methods)
  - ➡ rejects 45% of background events
  - ➡ keeps 90% of signal-like events

- Tested on events in DEP, Compton-edge, 2nbb spec

BEGe, background spectrum
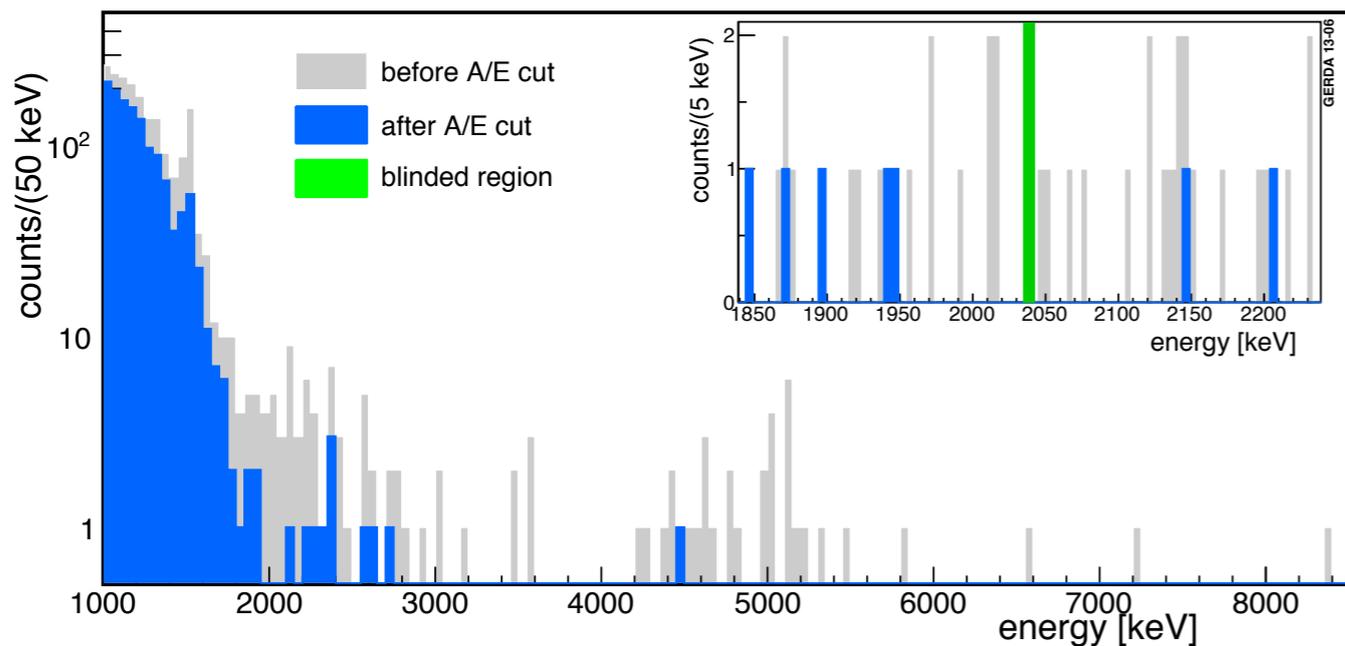
Coaxial, ^{228}Th calib spectrum

arXiv:1307.2610v1

After unblinding

counts/keV

GERDA 13-07

"Claim", PLB586 (2004)

$$T^{0\nu}_{1/2} = 1.19 \times 10^{25} \text{ yr (90\% C.L.)}$$
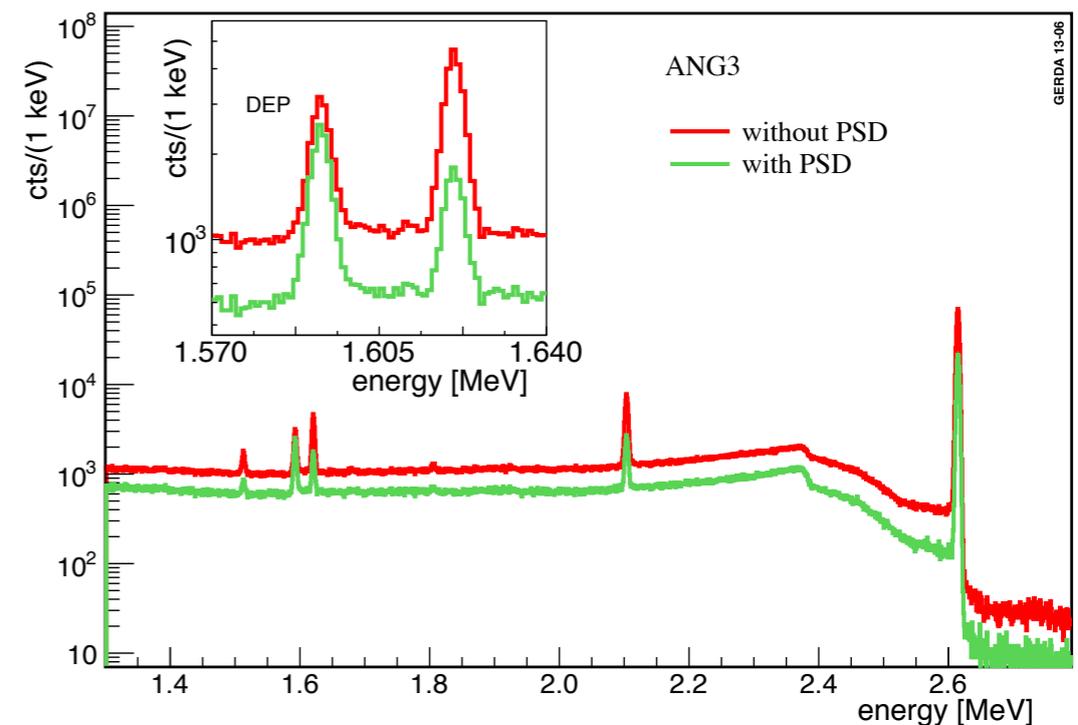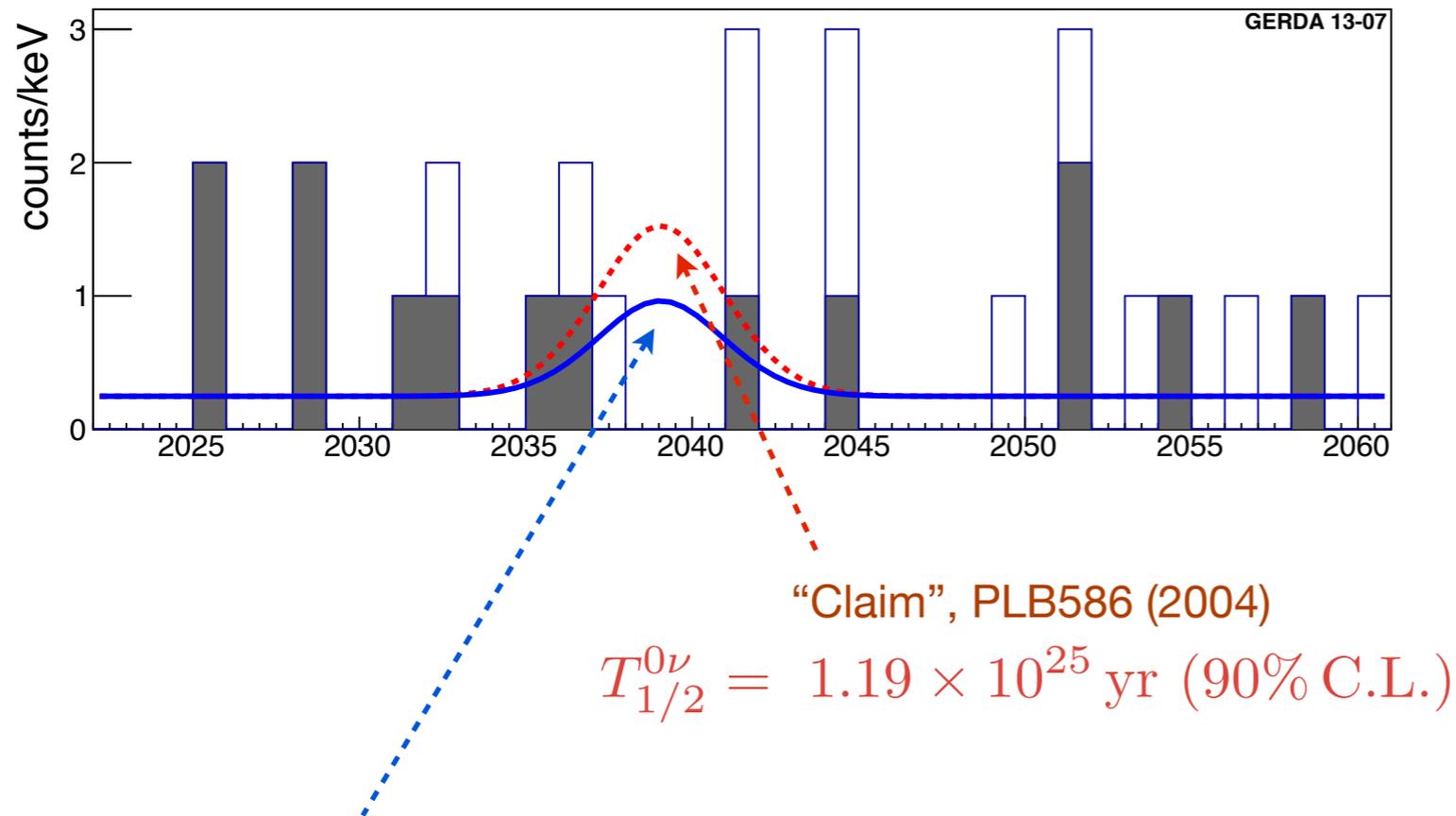
GERDA lower limit from PL fit of the 3 data sets, with constant term for background and Gaussian term for signal: best fit is $N_{signal} = 0$

$$T^{0\nu}_{1/2} > 2.1 \times 10^{25} \text{ yr (90\% C.L.)}$$

- Observed and predicted number of background events in the energy region Q ± 5 keV

	Observed	Predicted background
No PSD	7	5.1
PSD	3	2.5

- 5.9 ± 1.4 events are expected for "claim", and 2.0±0.3 signal events

Claim of evidence for 0vbb-decay:
signal: 28.8 ± 6.9 events
BG level: 0.11 counts/(kg keV yr)
HVKK et al., PLB 586 (2004) 198-212

After unblinding
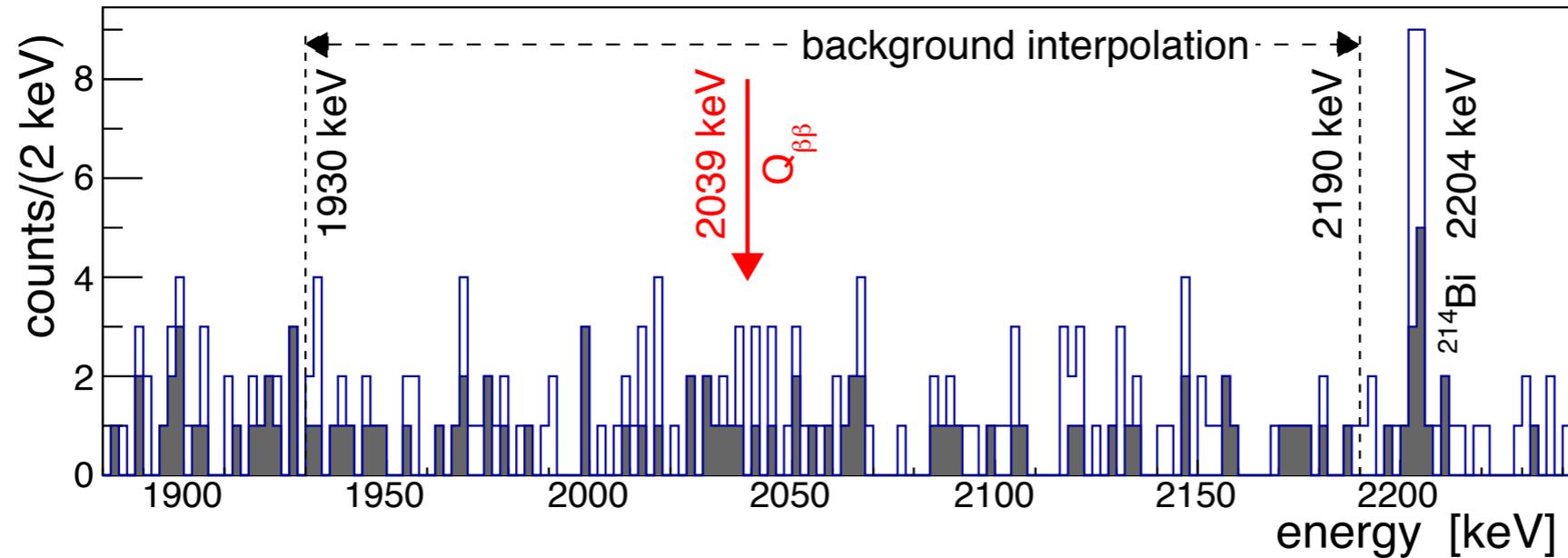
data set	$\mathcal{E}$[kg·yr]	$\langle\epsilon\rangle$	bkg	BI $^\dagger)$	cts	PSD
without PSD						passed
golden	17.9	0.688 ± 0.031	76	18 ± 2	5	
silver	1.3	0.688 ± 0.031	19	63^{+16}_{-14}	1	
BEGe	2.4	0.720 ± 0.018	23	42^{+10}_{-8}	1	
with PSD						
golden	17.9	$0.619^{+0.044}_{-0.070}$	45	11 ± 2	2	
silver	1.3	$0.619^{+0.044}_{-0.070}$	9	30^{+11}_{-9}	1	
BEGe	2.4	0.663 ± 0.022	3	5^{+4}_{-3}	0	

$^\dagger)$ in units of 10^{-3} cts/(keV·kg·yr).

data set	detector	energy	date	PSD
golden	ANG 5	2041.8	18-Nov-2011 22:52	no
silver	ANG 5	2036.9	23-Jun-2012 23:02	yes
golden	RG 2	2041.3	16-Dec-2012 00:09	yes
BEGe	GD32B	2036.6	28-Dec-2012 09:50	no
golden	RG 1	2035.5	29-Jan-2013 03:35	yes
golden	ANG 3	2037.4	02-Mar-2013 08:08	no
golden	RG 1	2041.7	27-Apr-2013 22:21	no

Bayesian analysis with flat prior on 1/T$_{1/2}$ $T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ yr (90% credible interval)

Summary and outlook

- No indication for a peak at Q = 2039 keV in GERDA phase I data

- GERDA provides a model-independent test of the signal claim

- Combined with HdM and IGEX:

$$T_{1/2}^{0\nu} > 3 \times 10^{25}\,\mathrm{yr}\ (90\%\,\mathrm{C.L.})$$

- This yields an upper limit on the effective Majorana neutrino mass of:

$$m_{\beta\beta} < 0.2 - 0.4\,\mathrm{eV}$$

- GERDA phase II will start later in 2013
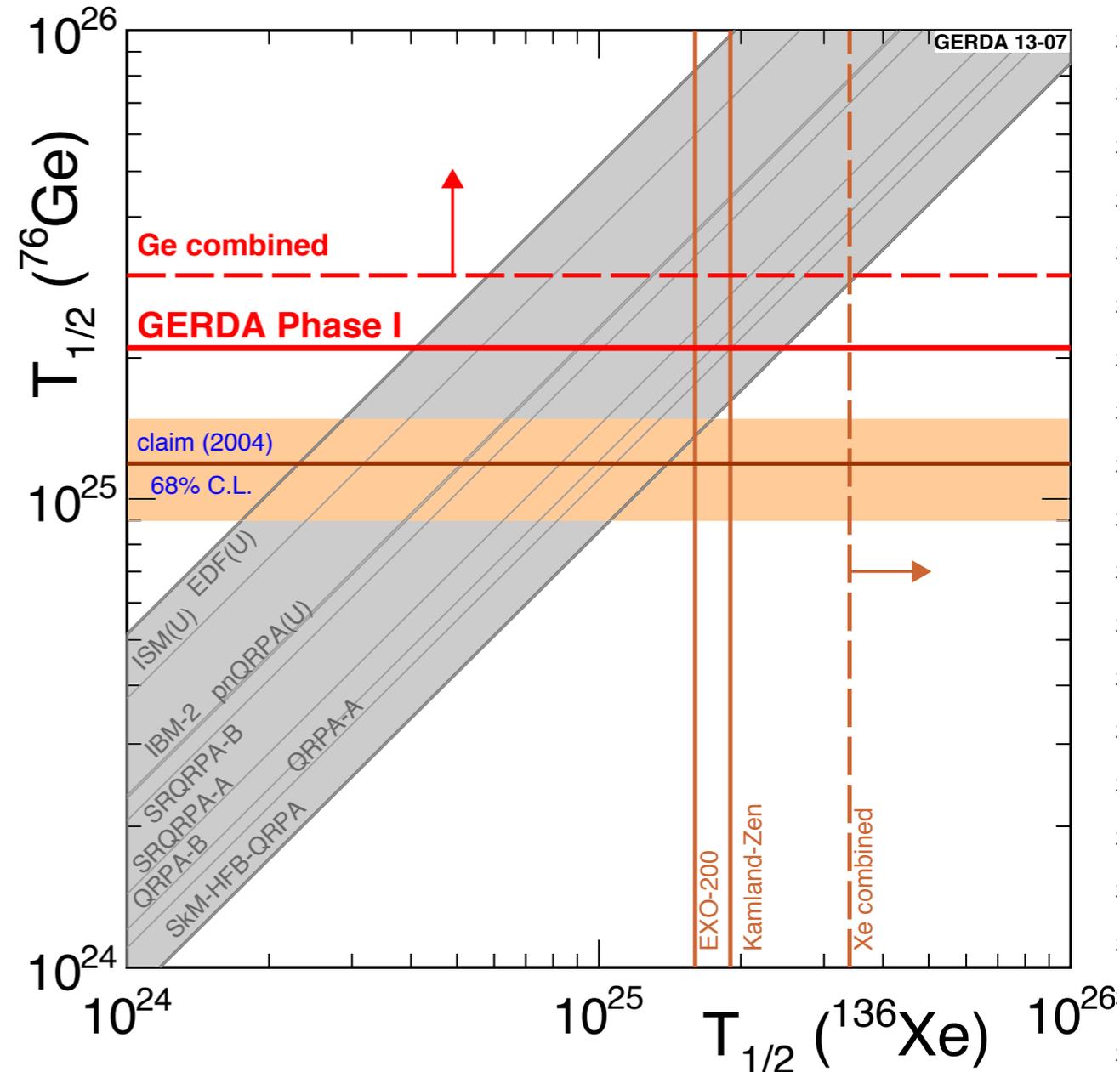
End

Combination with HdM and IGEX

Profile Likelihood - All ^{76}Ge data
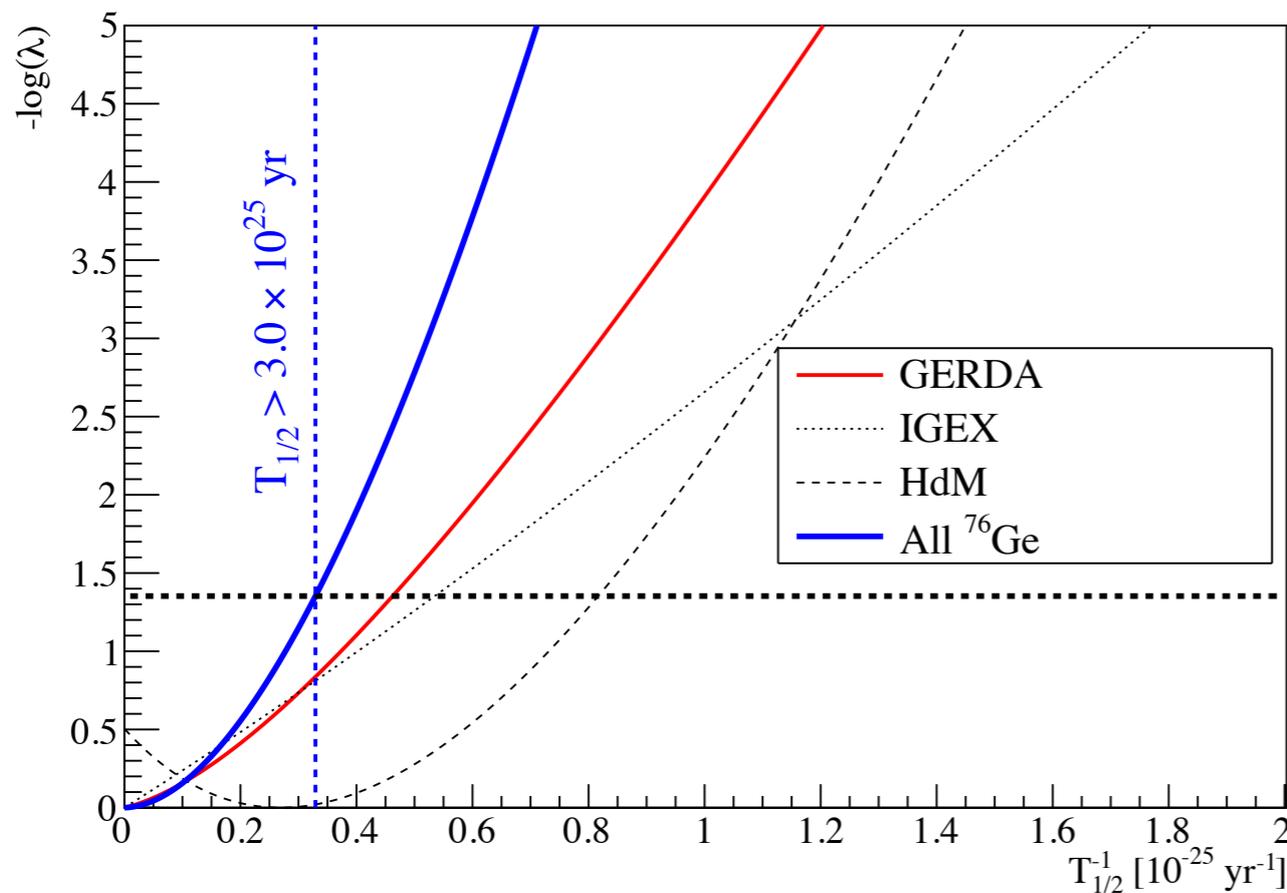
HdM: Eur. Phys. J. A 12, 147 (2001)
IGEX: Phys. Rev. D 65, 092007 (2002),
Phys. Rev. D 70 078302 (2004)

$$T_{1/2}^{0\nu} > 3.0 \cdot 10^{25} \text{ yr} \quad (90\% \text{ C.L.})$$

Identical limits with
Frequentists & Bayesian analysis

- Bayes factor: P(H1)/P(H0)=2×10^{-4} strongly disfavors claim
- Comparison is independent of NME and physical mechanism which generates 0νββ

Two-neutrino double beta decay

- The 2nbb half life derived when using the full background model:

model	$\mathcal{E}$ [kg·yr]	$T^{2\nu}_{1/2} \cdot 10^{21}$ yr
GOLD-coax minimum	15.40	$1.92^{+0.02}_{-0.04}$
GOLD-coax maximum	15.40	$1.92^{+0.04}_{-0.03}$
GOLD-nat minimum	3.13	$1.74^{+0.48}_{-0.24}$
SUM-BEGe	1.80	$1.96^{+0.13}_{-0.05}$
Analysis in Ref. [18]	5.04	$1.84^{+0.09}_{-0.08}{}_{fit}{}^{+0.11}_{-0.10}{}_{syst}$

Background in the 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]

F⛰m counts to half life

$$T_{1/2}^{0\nu} = \frac{\ln 2 \cdot N_A}{m_{enr} \cdot N^{0\nu}} \cdot \mathcal{E} \cdot \epsilon$$

$$\epsilon = f_{76} \cdot f_{av} \cdot \varepsilon_{fep} \cdot \varepsilon_{psd}$$

N_A: Avogadro number
E: exposure
ε: exposure averaged efficiency
m_{enr}: molar mass of enriched Ge
$N^{0\nu}$: signal counts / limit

f_{76}:   enrichment fraction
f_{av}:   fraction of active detector volume
ε_{fep}: full energy peak efficieny for 0νββ
ε_{psd}: signal acceptance

Data set	Exposure (kg yr)
Golden-coax	17.9
Silver-coax	1.3
BEGe	2.4

	$\langle f_{76} \rangle$	$\langle f_{av} \rangle$	$\langle \varepsilon_{fep} \rangle$	$\langle \varepsilon_{psd} \rangle$	$\langle \varepsilon \rangle$
Coax	0.86	0.87	0.92	0.90 +0.05/ -0.09	0.619 +0.044/-0.070
BEGe	0.88	0.92	0.90	0.92 ±0.02	0.663 ±0.022

Expected sensitivity for <m$_{\beta\beta}$>
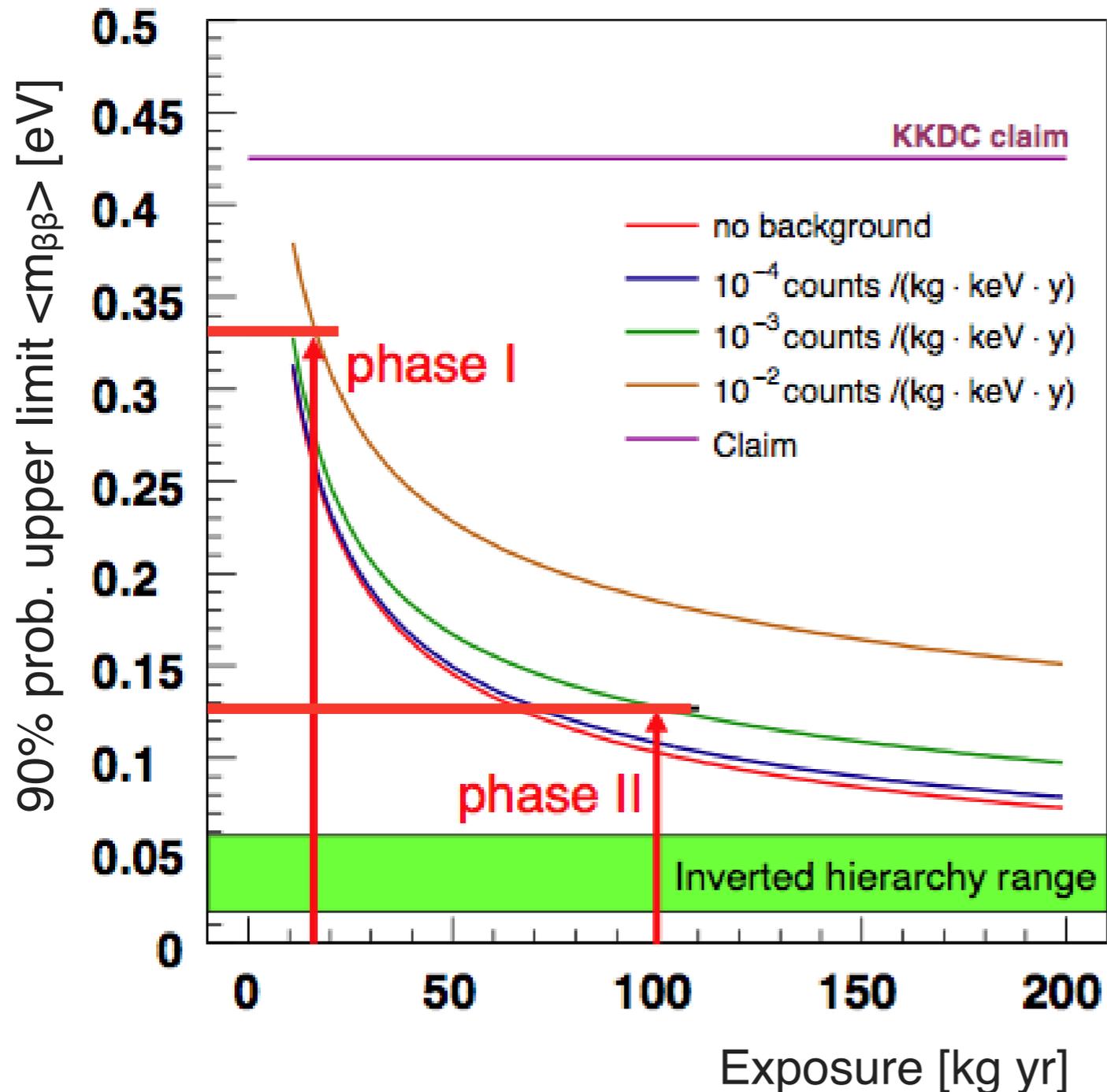
Klapdor-Kleingrothaus HM signal

$$\left|M^{0\nu}\right| = 3.92$$

V.A. Rodin et al., Nucl. Phys. A 366 (2006) 107-131, Nucl. Phys. A793 (2007) 213-215

B = 10^{-2} events/(kg keV yr)

B = 10^{-3} events/(kg keV yr)

Ge detectors: isotopic composition

Table 2 The relative number of nuclei for the different isotopes is shown for the different detector batches. The isotopic composition of the depleted material is the average of measurements by the collaboration and ECP; that for natural germanium is given for comparison

detector batch	Ref.	germanium isotope				
		70	72	73	74	76
natural	[64]	0.204(2)	0.273(3)	0.078(1)	0.367(2)	0.078(1)
HDM–ANG 1	[73]	0.0031(2)	0.0046(19)	0.0025(8)	0.131(24)	0.859(29)
IGEX	[63]	0.0044(1)	0.0060(1)	0.0016(1)	0.1329(1)	0.8551(10)
GERDA depleted		0.223(8)	0.300(4)	0.083(2)	0.388(6)	0.006(2)
GERDA Phase II ⋆	[66]	0.0002(1)	0.0007(3)	0.0016(2)	0.124(4)	0.874(5)
MAJORANA	[74]	0.00006	0.00011	0.0003	0.0865	0.914

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)