Results on $0\nu\beta\beta$ decay of ^{76}Ge from the GERDA experiment

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Workshop on Germanium-Based Detectors and Technologies, Vermillion 2014

Outline

- neutrinoless double beta decay
- the GERDA experiment
- Phase I
  - performance
  - results
- Phase II: a status update
- summary and outlook

Neutrinoless double beta decay

2νββ

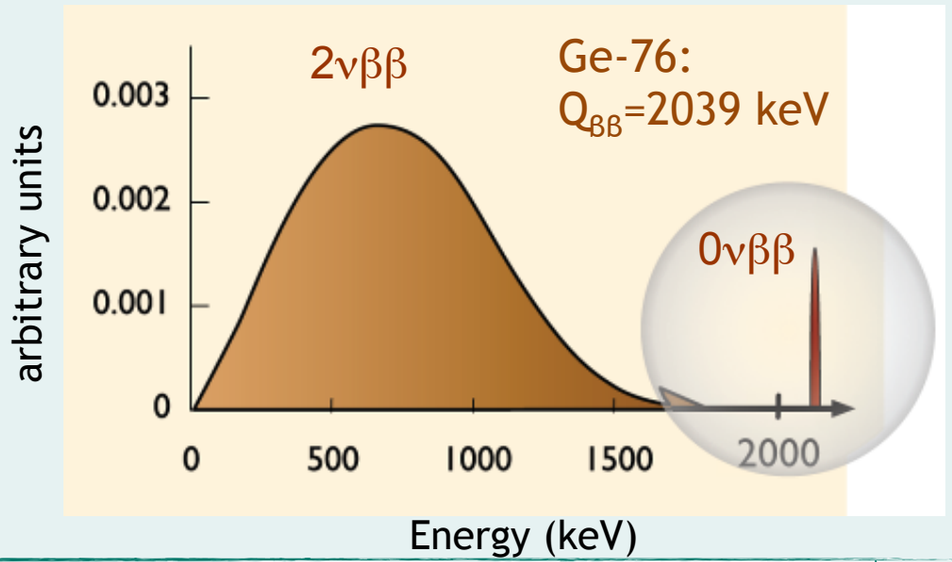
$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$$

- Standard Model allowed process
- observed for several isotopes (^{76}Ge, ^{130}Te, ^{136}Xe …)
- $T_{1/2}$ in range 10^{19} - 10^{24} yr

0νββ

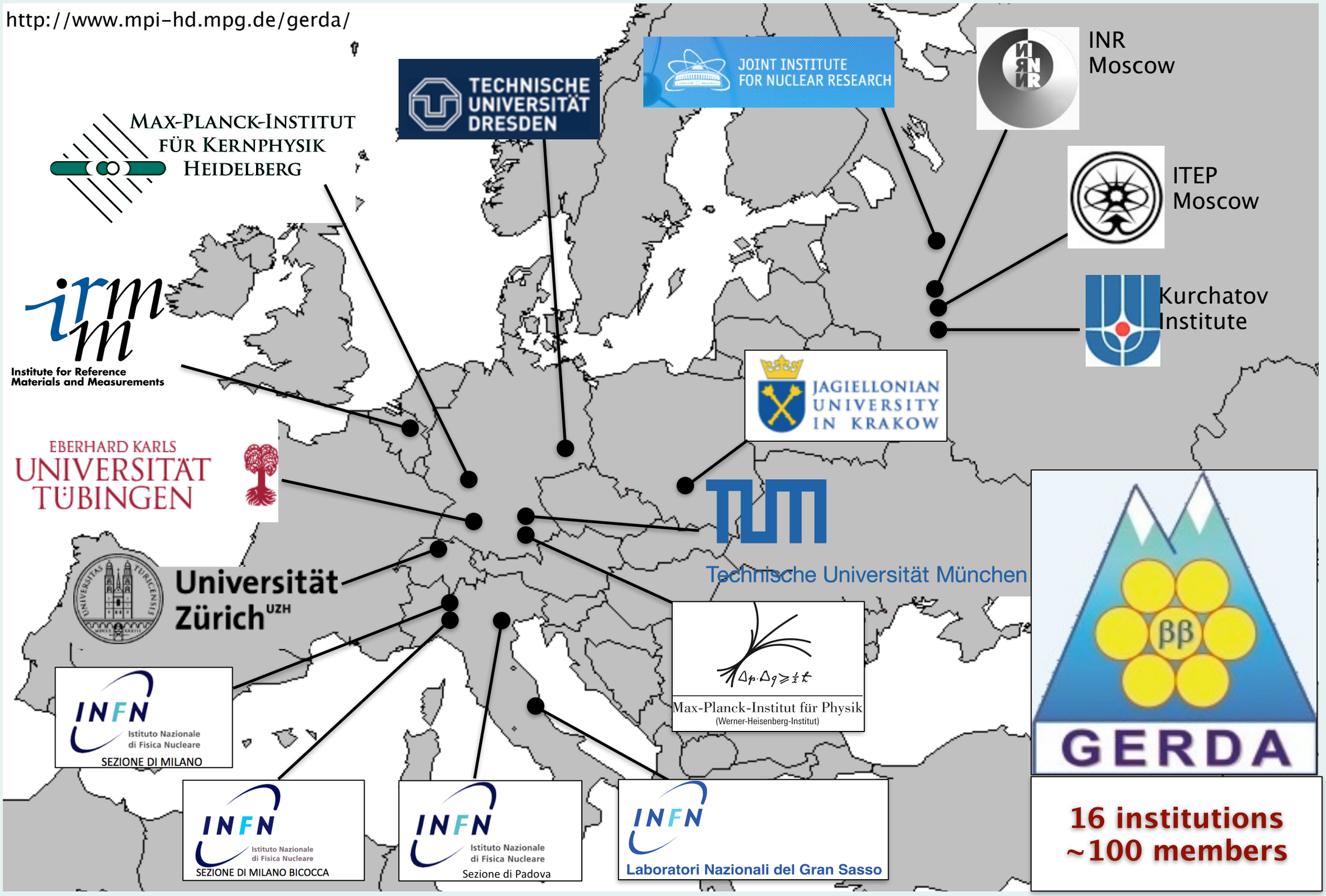
$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$

- lepton number violation ΔL=2
- physics beyond the Standard Model
  (light Majorana ν, R-handed weak currents, SUSY particles …)
- ν have Majorana character
- mass scale and hierarchy
- $T_{1/2}$ limits in the range 10^{21} - 10^{26} yr
  (one claim for signal by HdM subgroup)

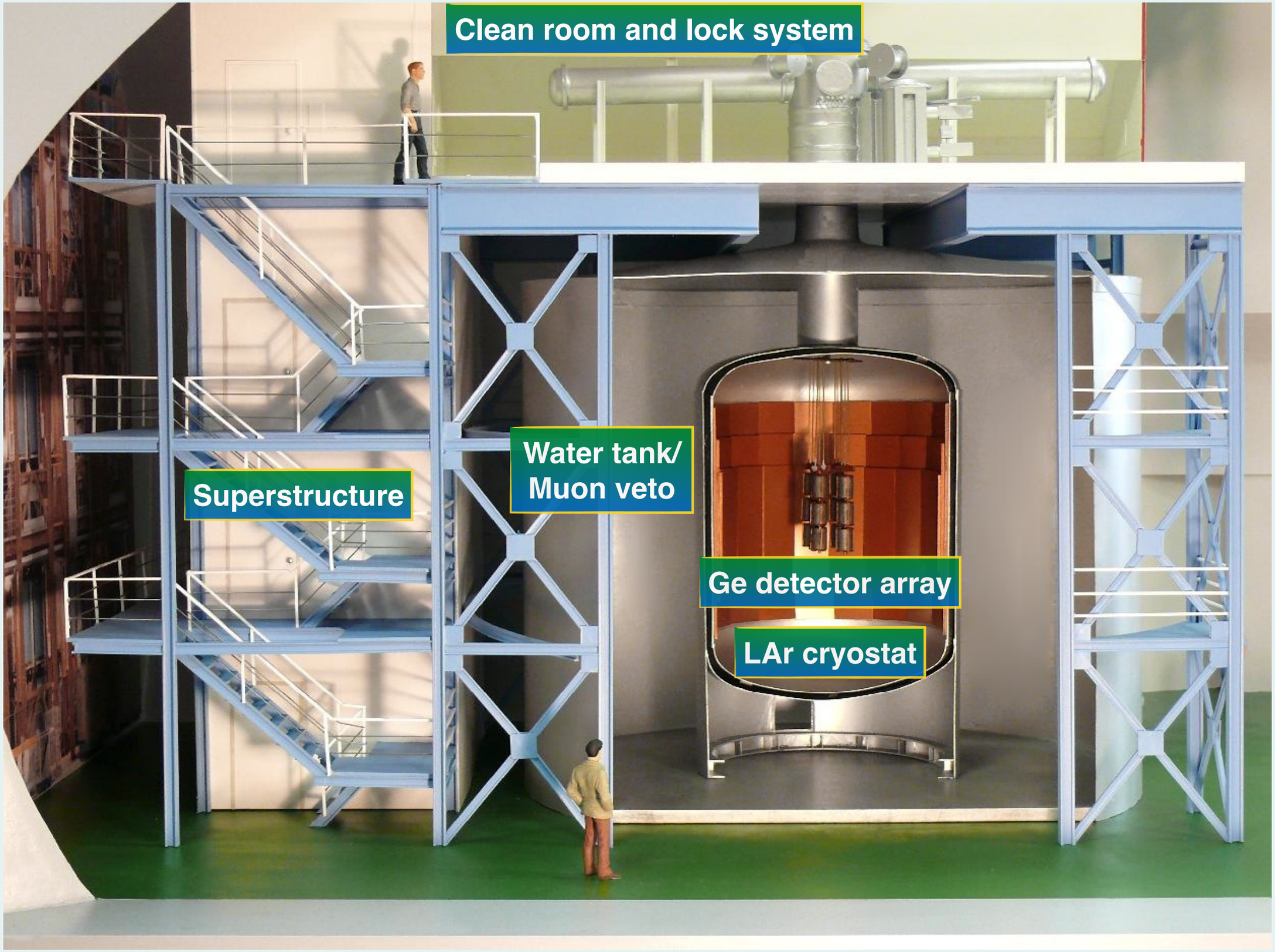


The GERDA collaboration

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

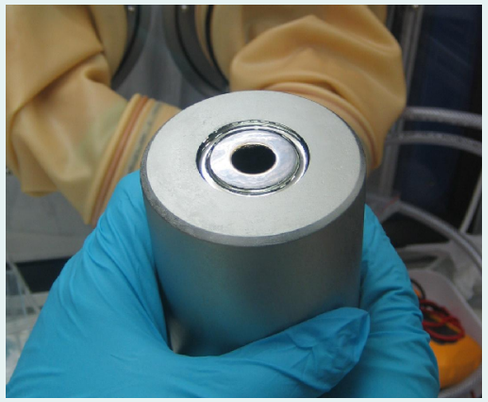


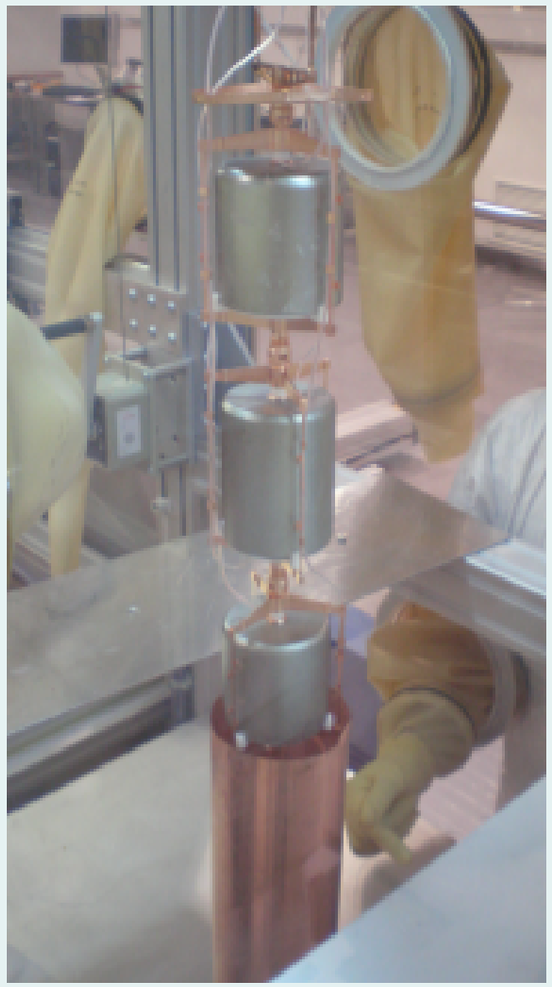
The GERDA experiment



Phase I detectors

Semi-coaxial



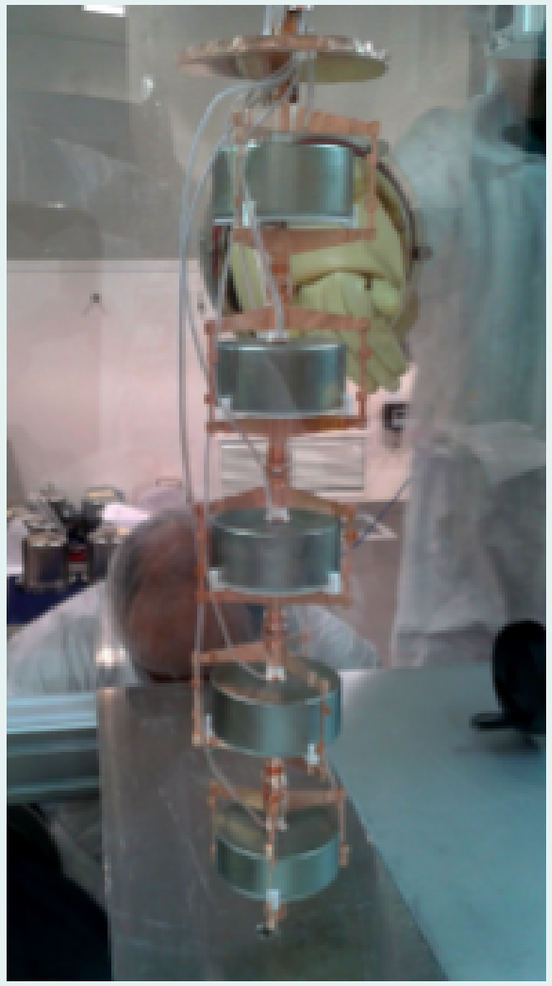


8 enriched semi-coaxial p-type HPGe detectors (refurbished HdM and IGEX diodes)

~86% enrichment fraction

14.6 kg

BEGe

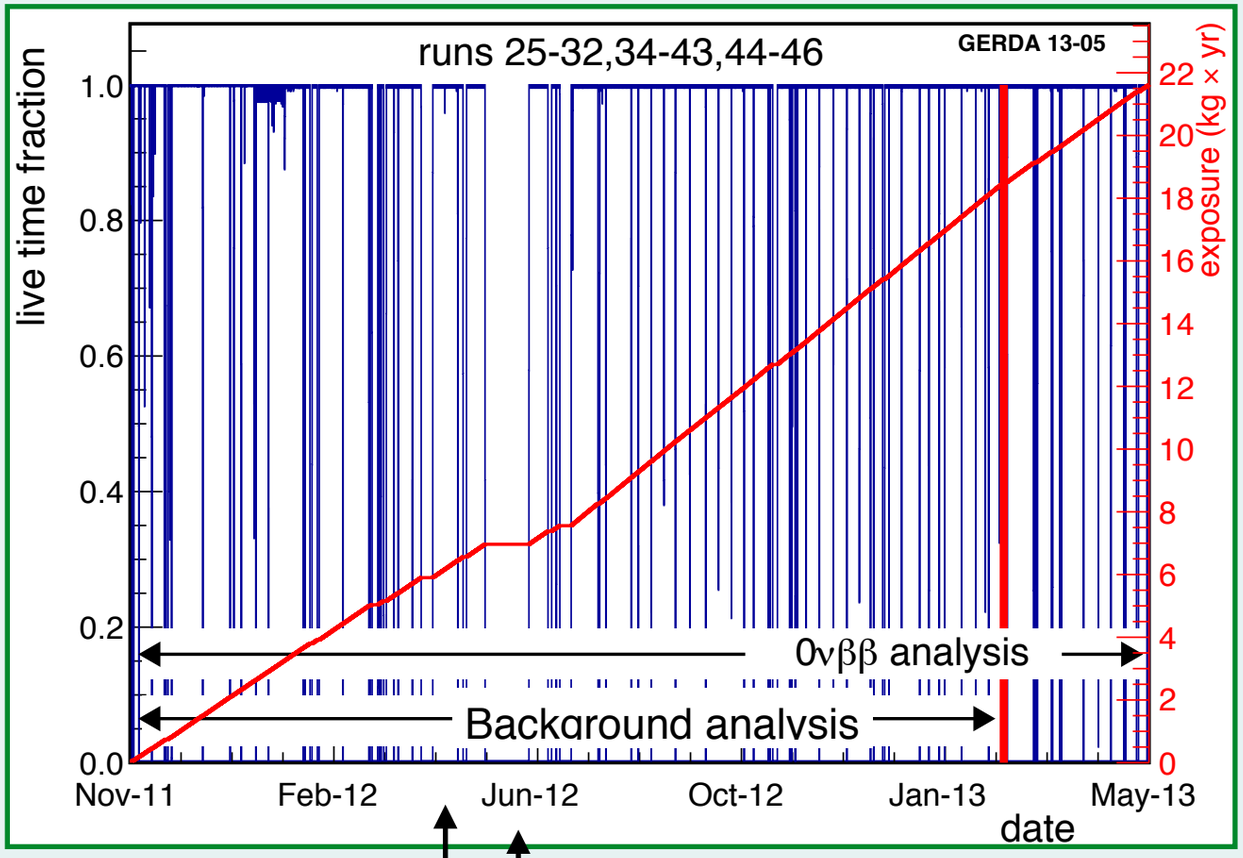


5 enriched p-type BEGe detectors

~88% enrichment fraction

3.0 kg

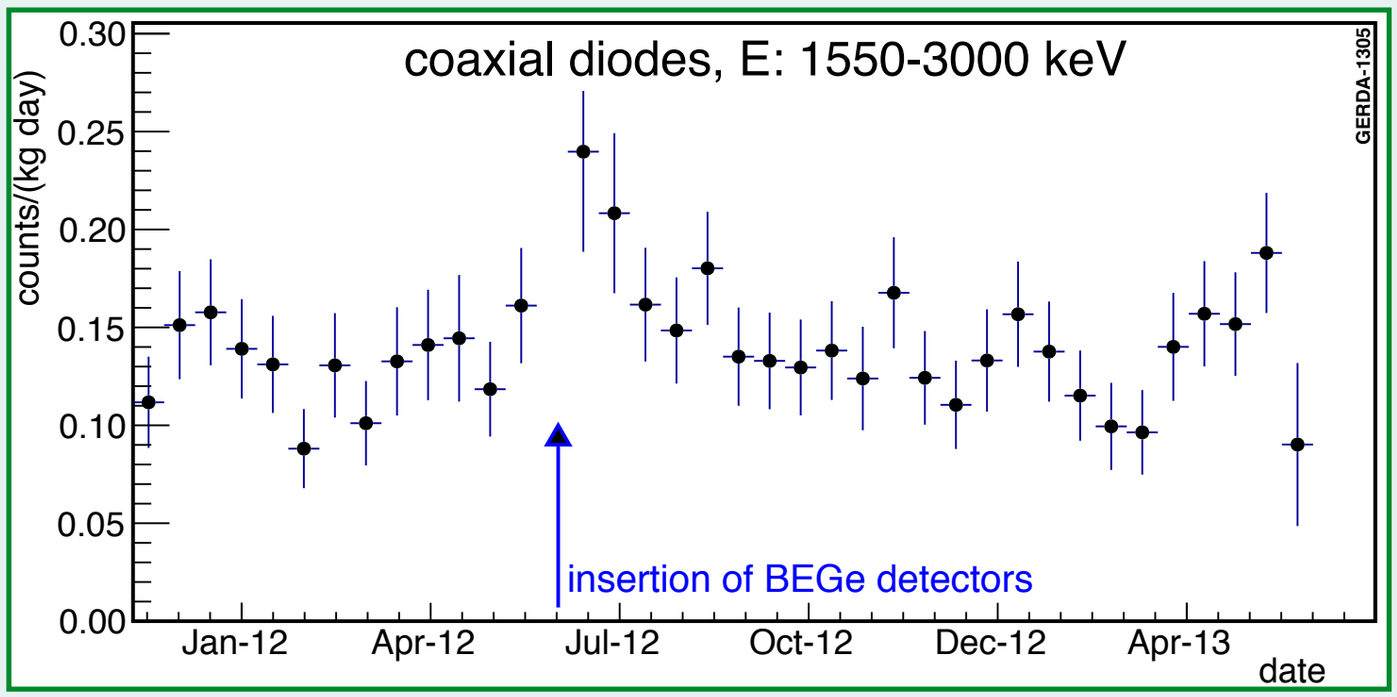
Overview of Phase I data taking



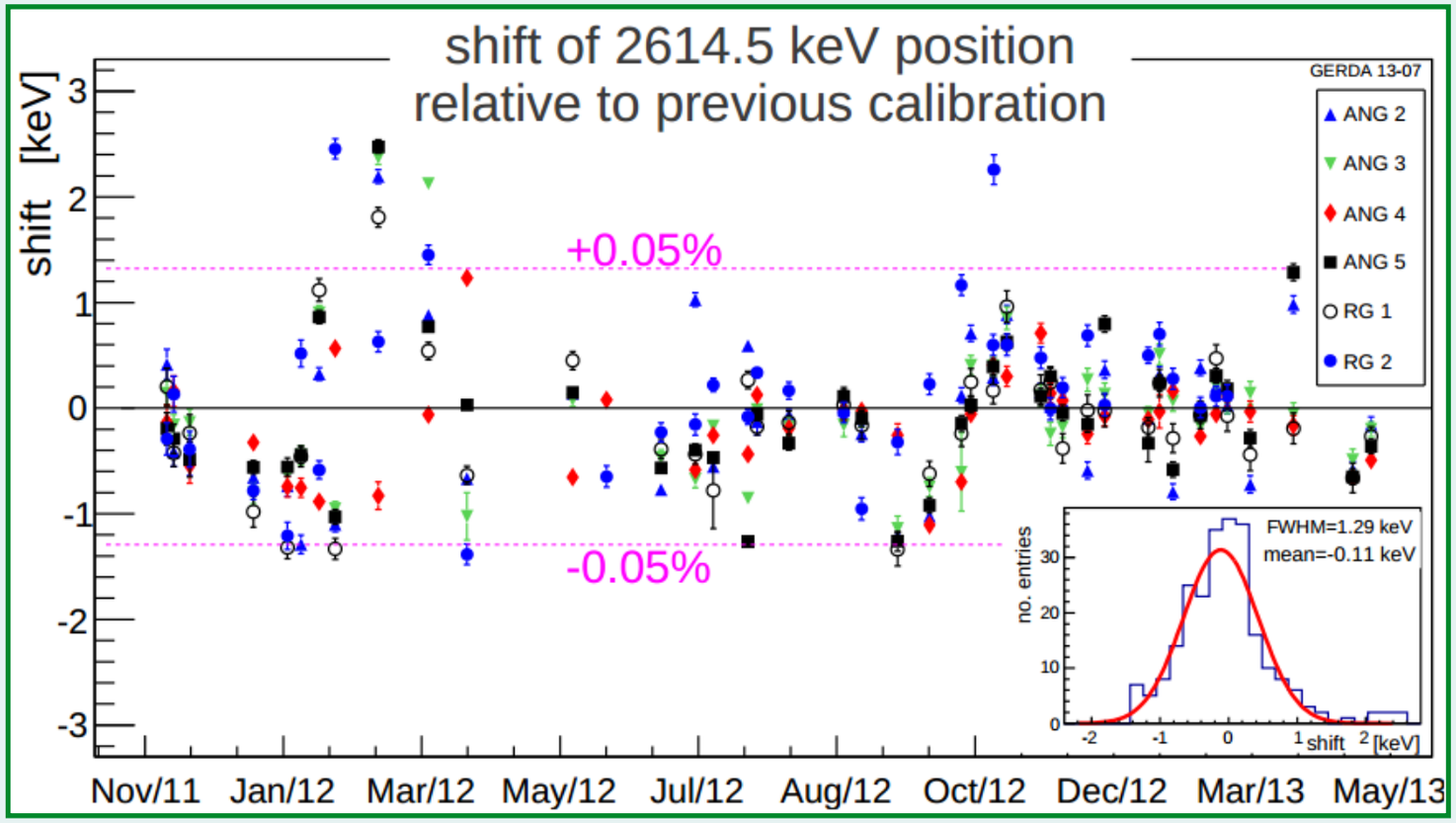
Data set	Exposure (kg yr)
Coaxial (Golden)	17.9
Coaxial (Silver)	1.3
BEGe	2.4
Total	**21.6**

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

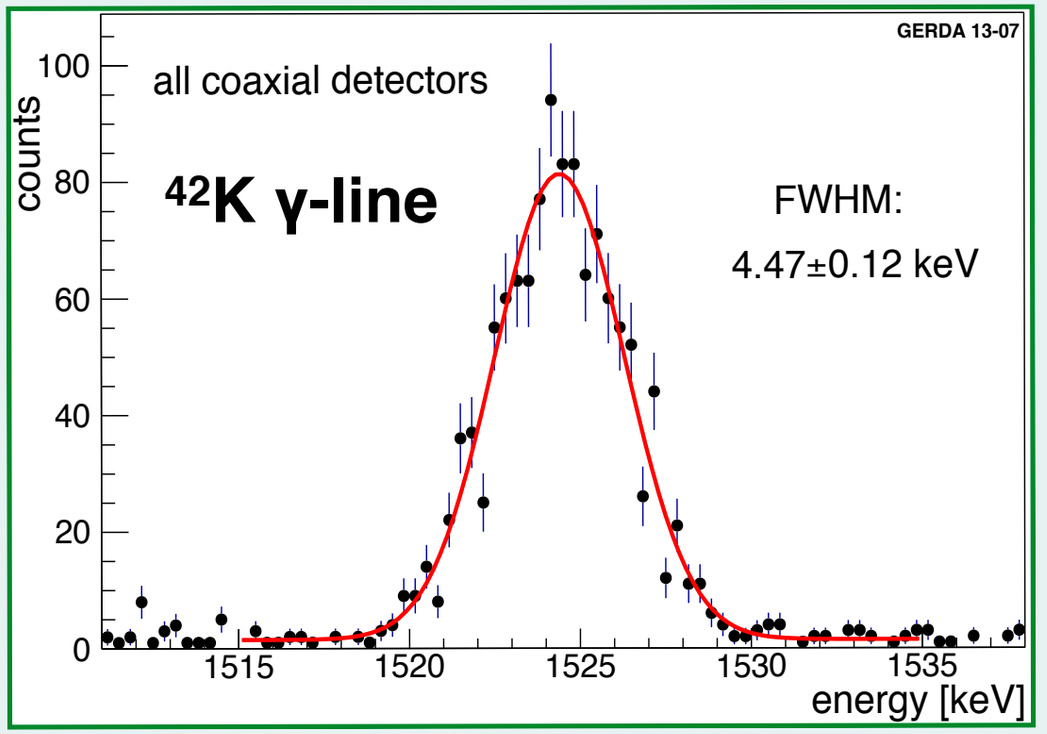
- data taking: Nov11-May13 (492 days)
- average duty cycle 88%
- bi-weekly calibration ^{228}Th (“spikes”)

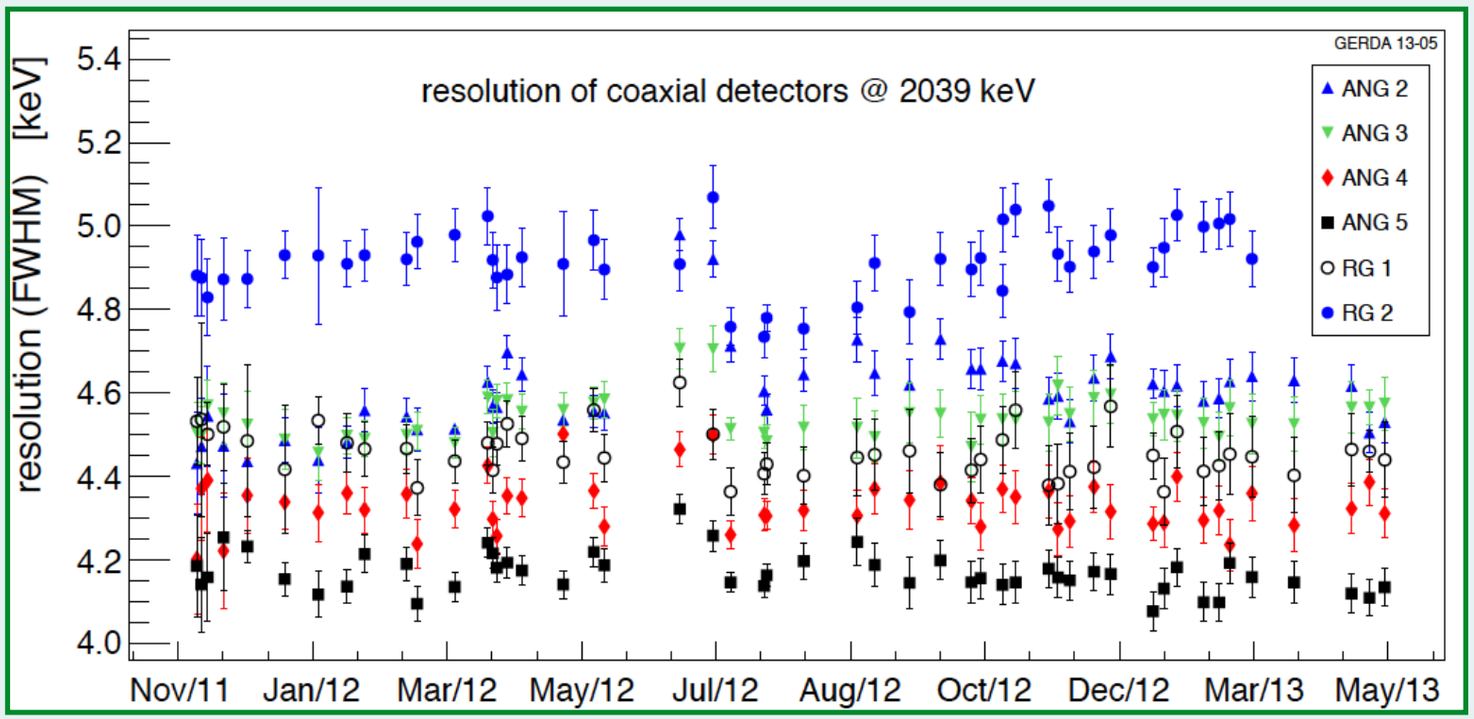


Calibration and energy resolution



- energy shift between successive calibrations less than 1 keV at Q_{bb}
- energy resolution stable



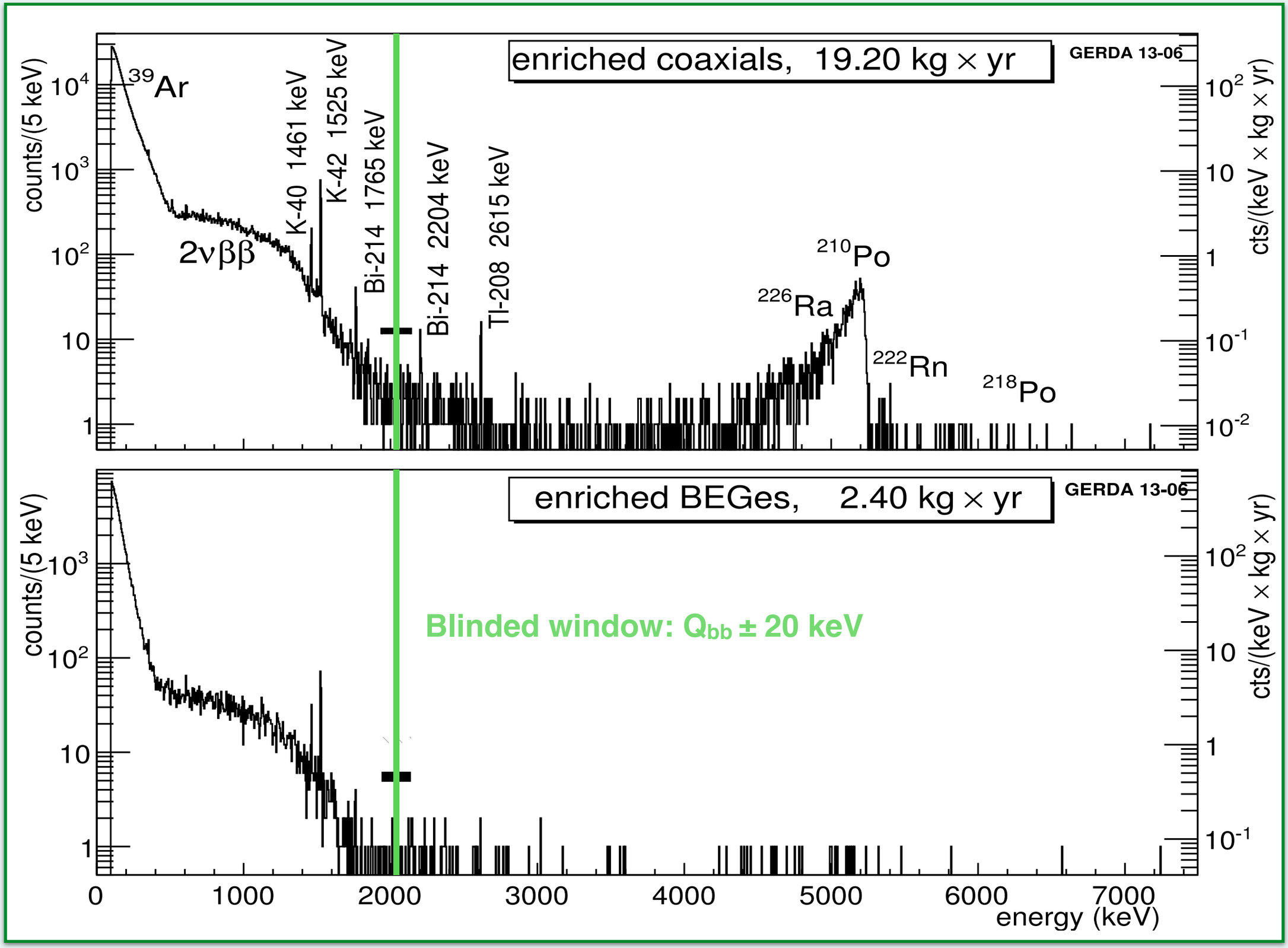


mean energy resolution (FWHM) at Q_{bb}=2039 keV

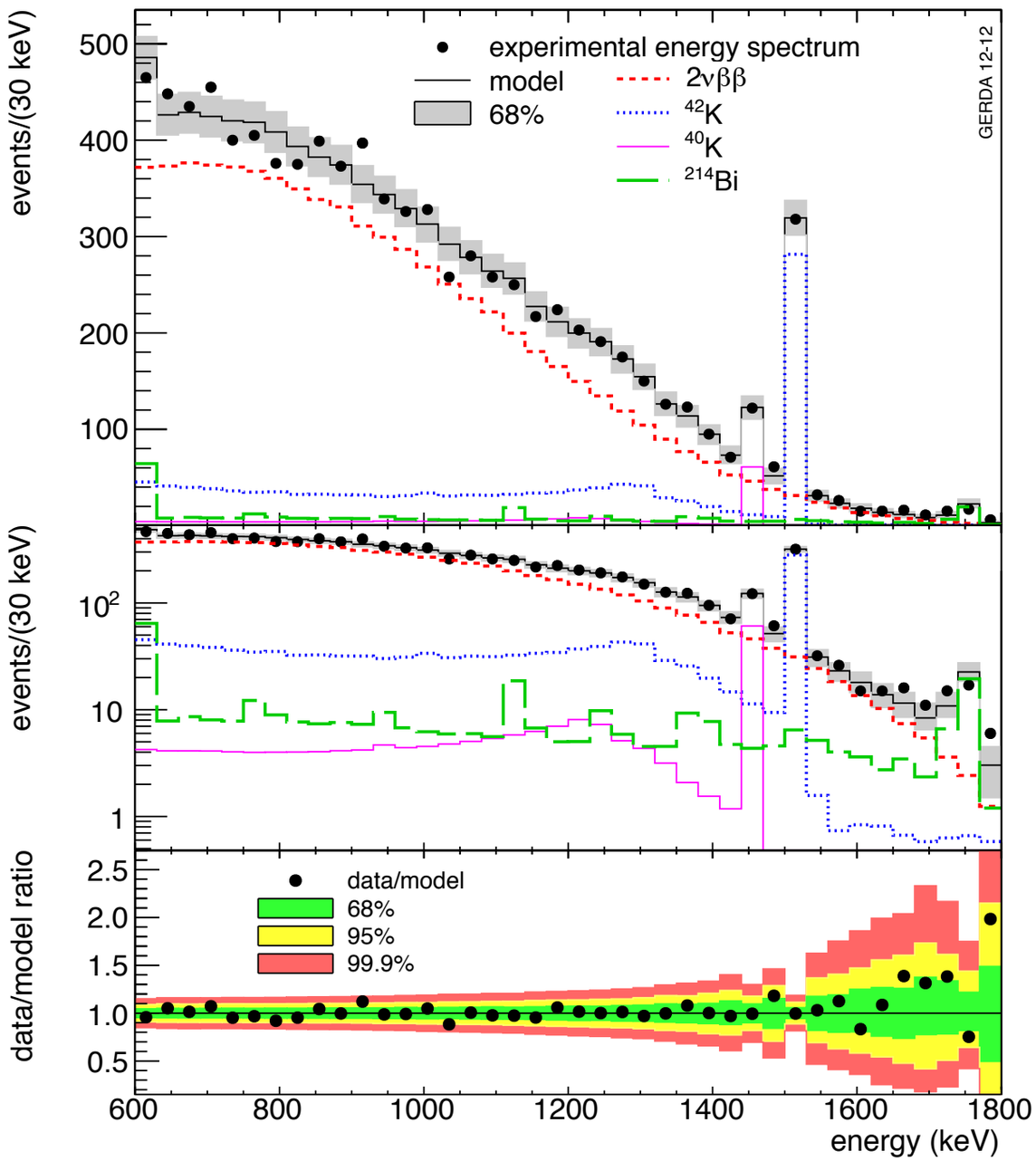
Semi coax 4.8±0.2 keV

BEGe 3.2±0.2 keV

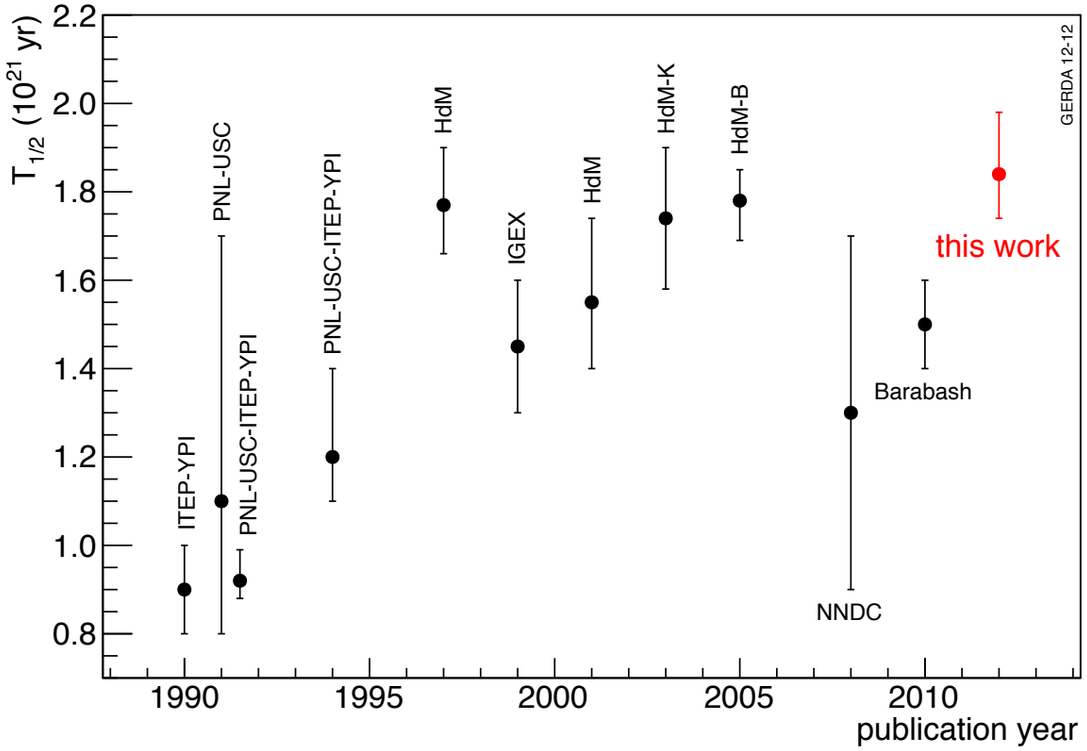
Phase I energy spectrum



Measurement of the 2νββ half-life of ^{76}Ge



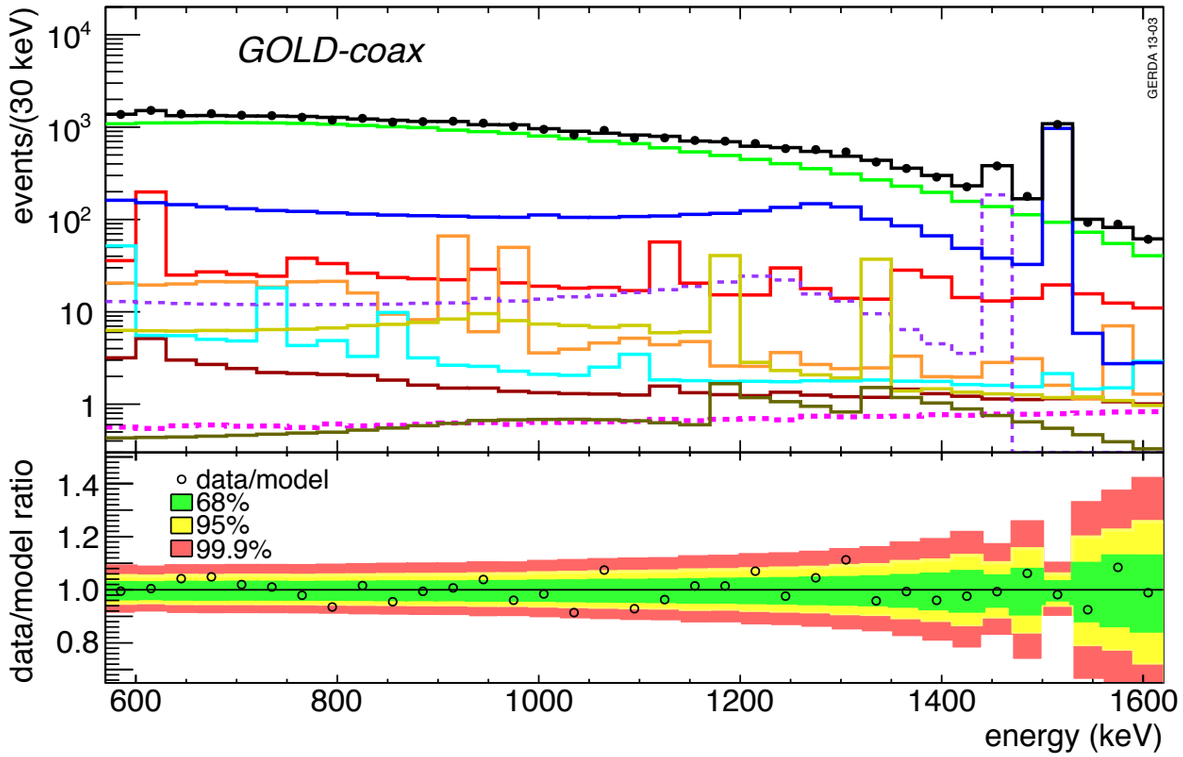
- 5.04 kg yr exposure
- binned ML fit (600-1800 keV)
- fit parameters (32):
  - active detector masses (6+1)
  - enrichment fractions (6)
  - background contributions (3x6)
- $T_{1/2}$ common to all detectors

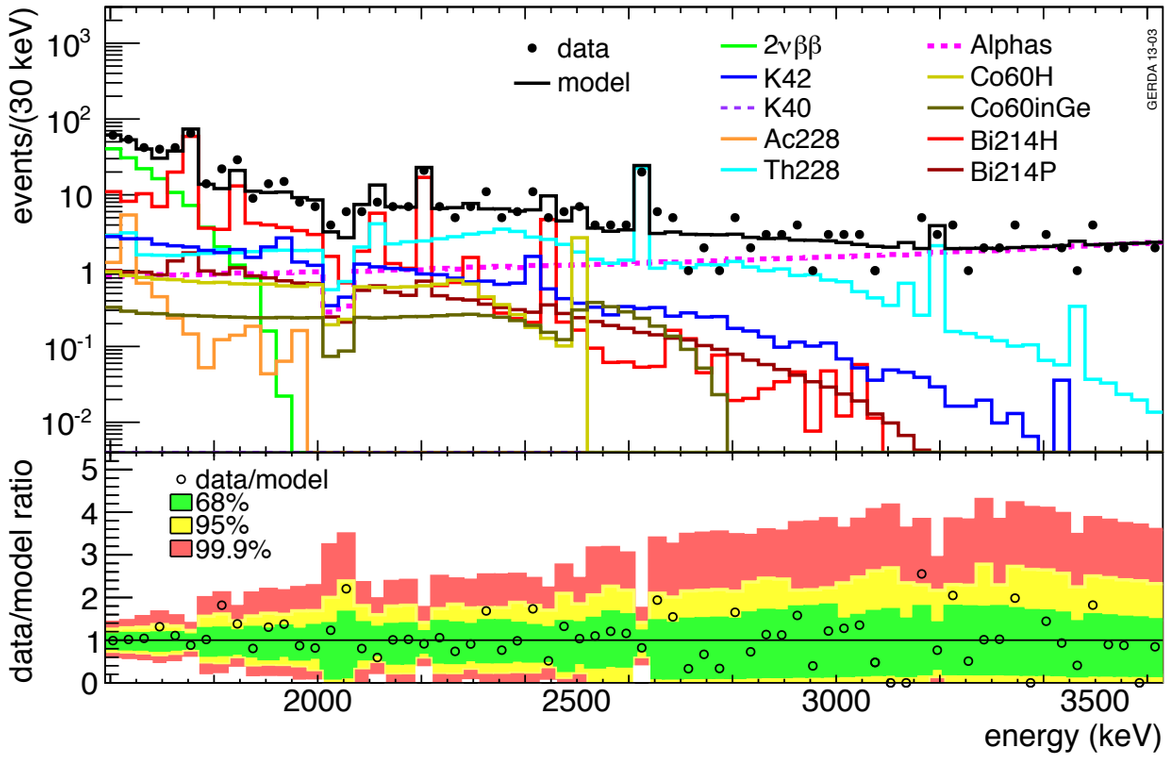


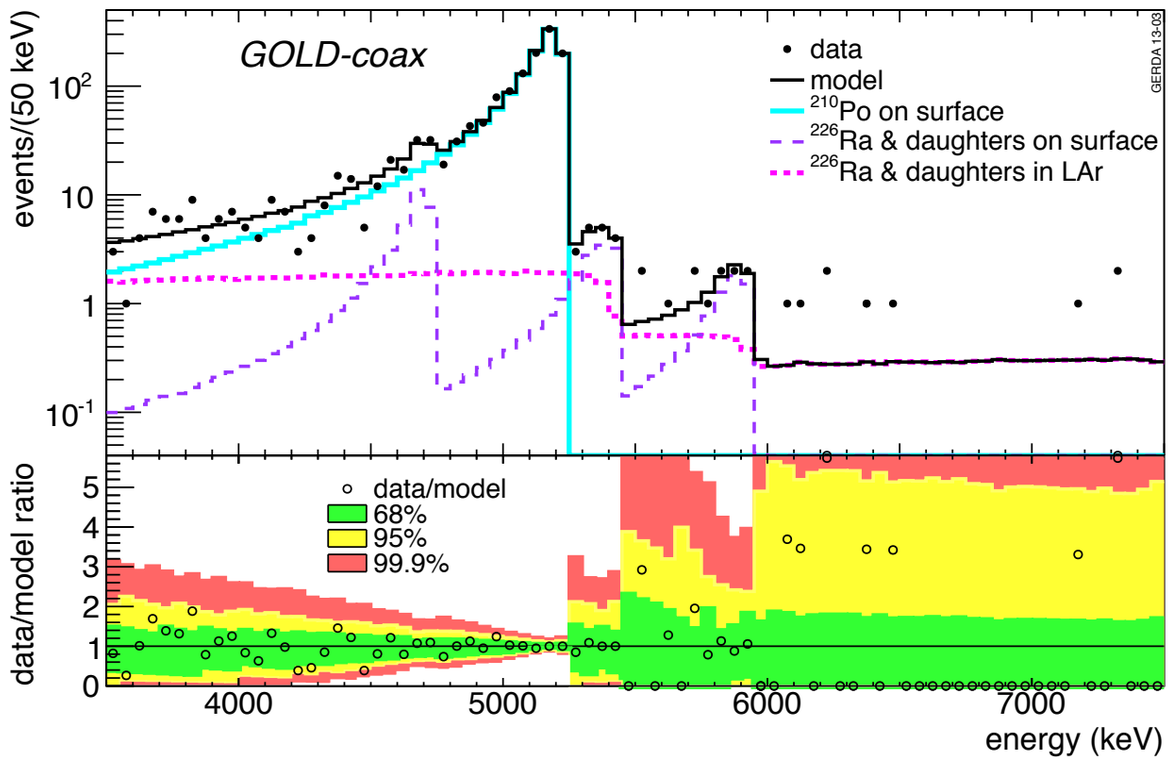
$$T_{1/2}^{2\nu} = \left(1.84^{+0.09\ +0.11}_{-0.08\ \text{fit}\ -0.06\ \text{syst}}\right) \times 10^{21}\,\text{yr} = \left(1.84^{+0.14}_{-0.10}\right) \times 10^{21}\,\text{yr}$$

J. Phys. G 40 (2013) 035110

Background modelling







spectral fit with simulated spectra (570-7500keV, blind at Q_{bb} ± 20 keV)

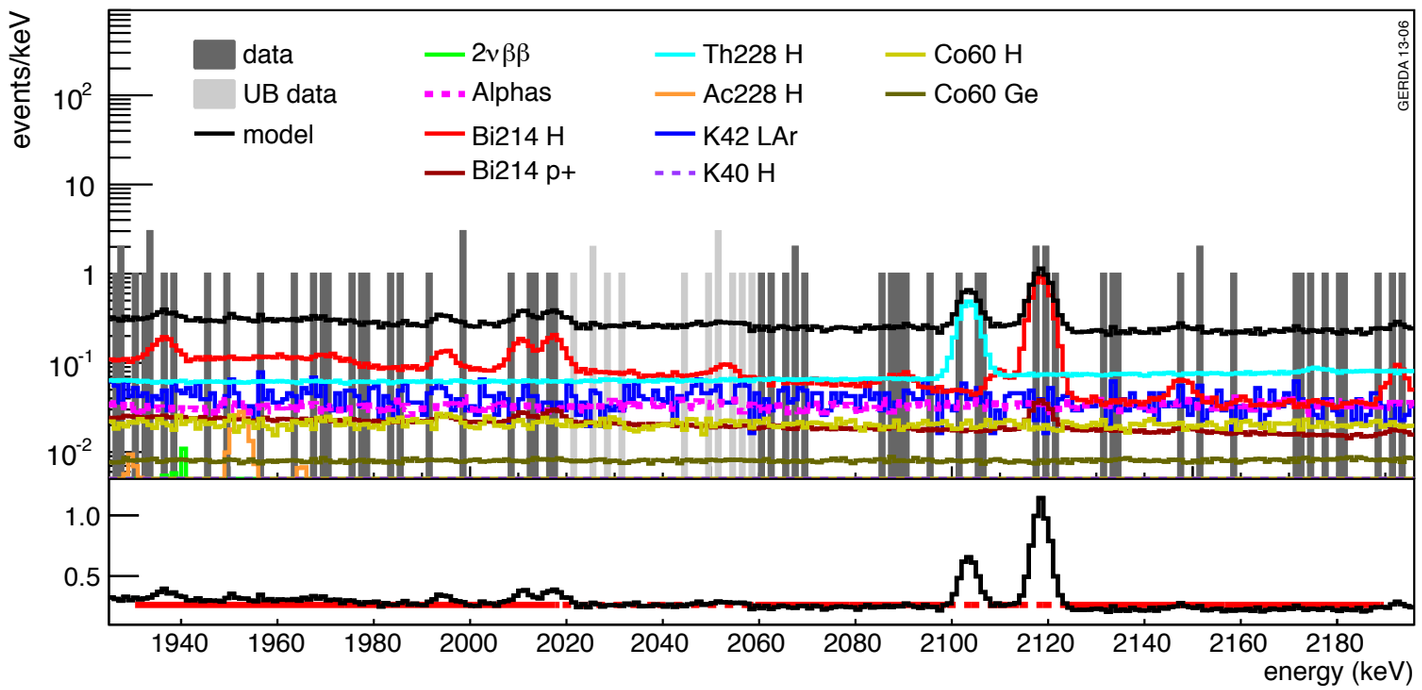
Contributions at Q_{bb}

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

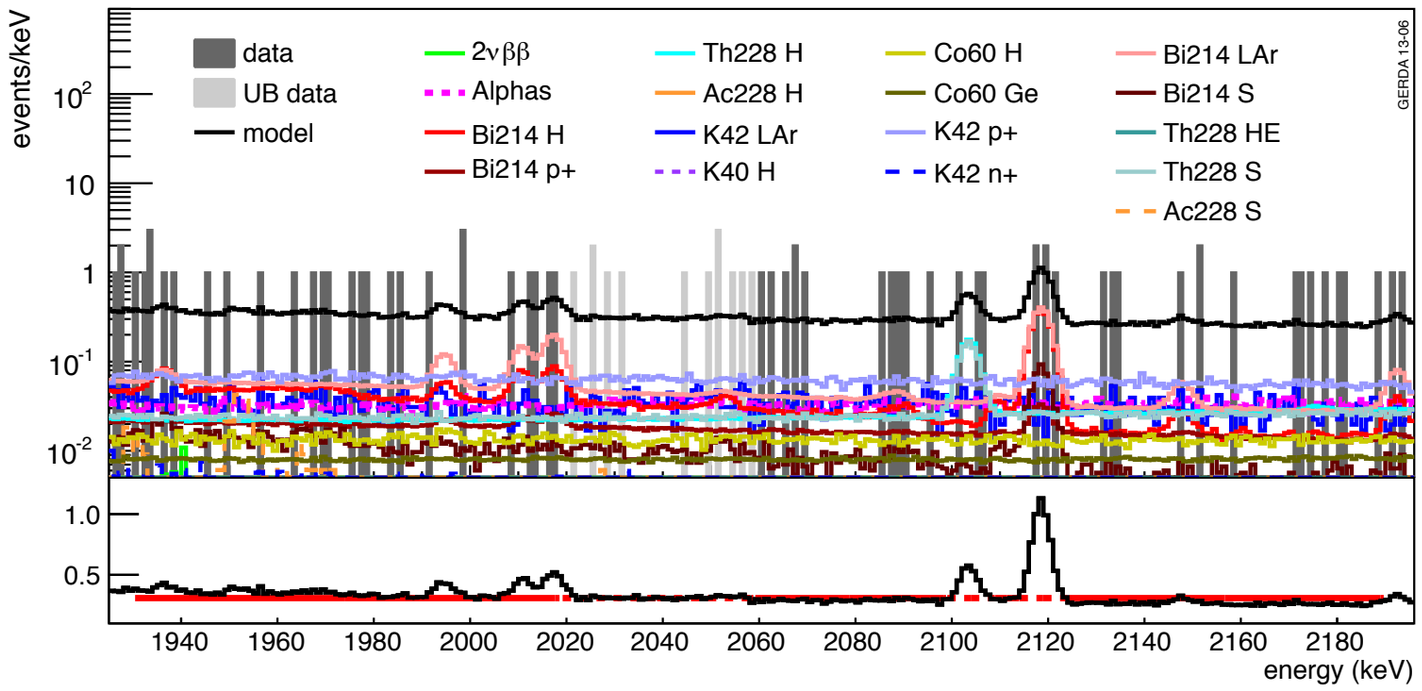
Eur. Phys. J. C (2014) 74:2764

Background Index at Q_{bb}

Minimal model (well-motivated contributions)

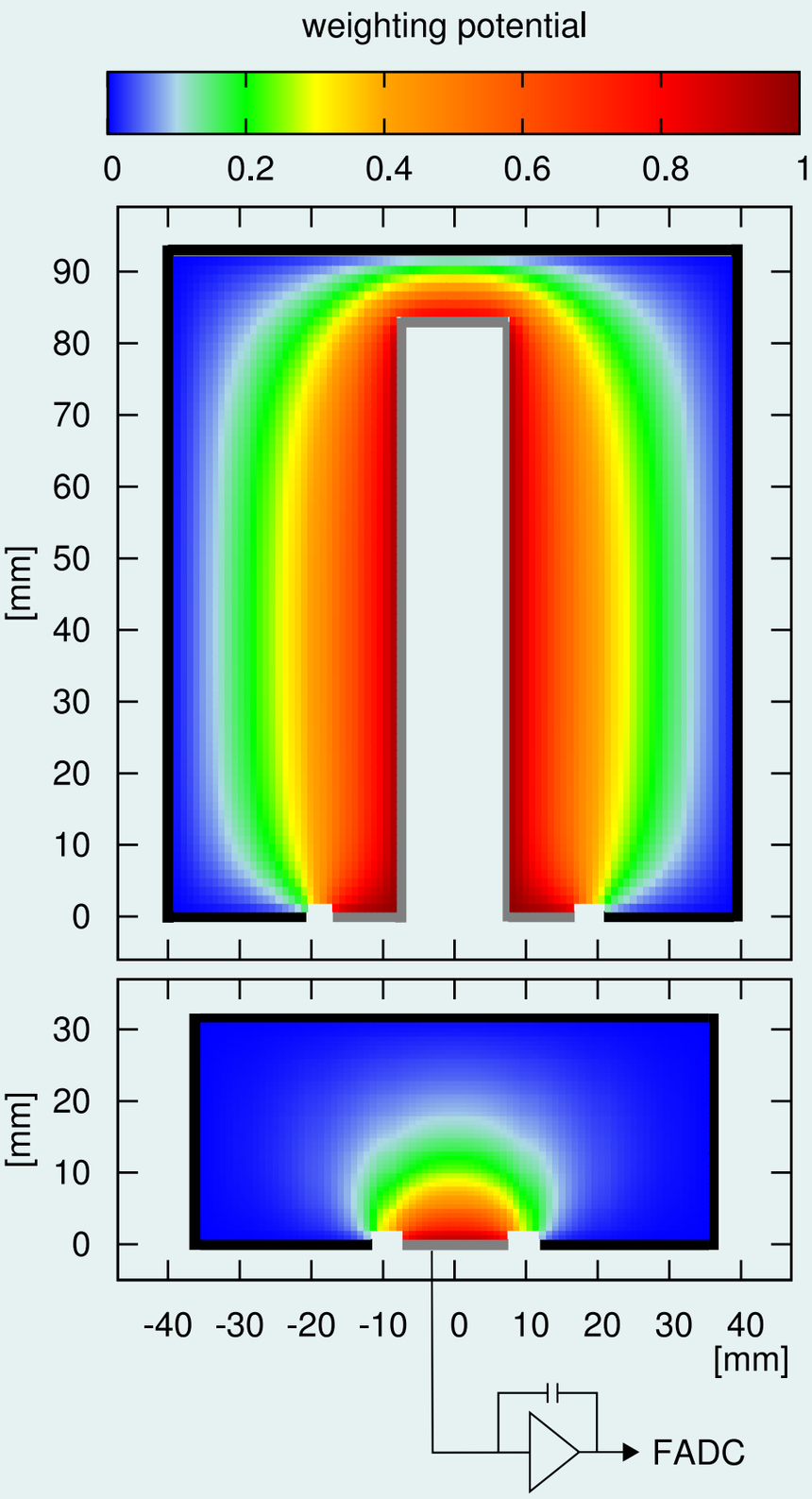


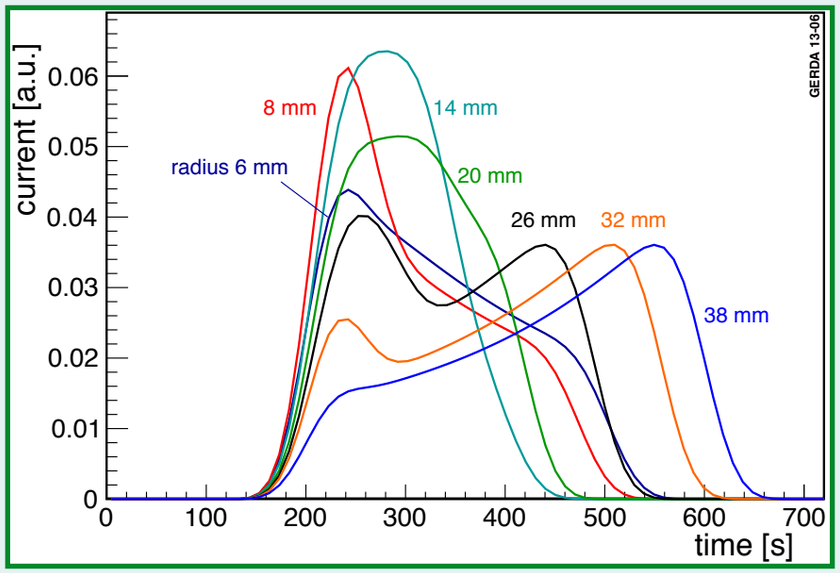
Maximum model (additional contributions)



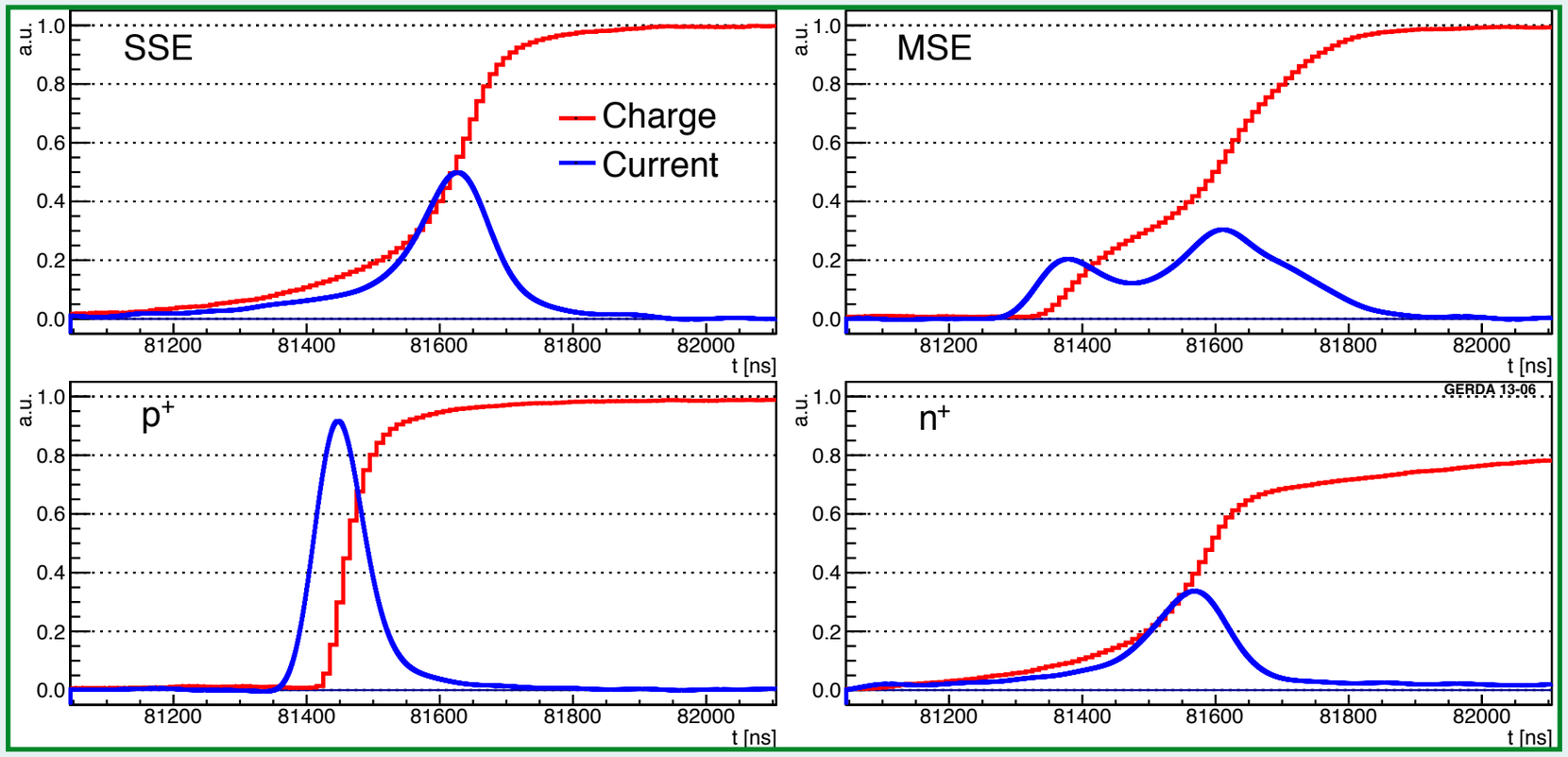
- no γ line expected around Q_{bb}
- agreement after partial unblinding
- spectrum can be modelled with flat background (1930-2190 keV) excluding ^{214}Bi (2104 keV) and ^{208}Tl (2119 keV)
- background index at Q_{bb} (no PSD) $(17.6\text{-}23.8)\times10^{-3}$ cts/(keV kg yr)

Pulse Shape Discrimination Methods



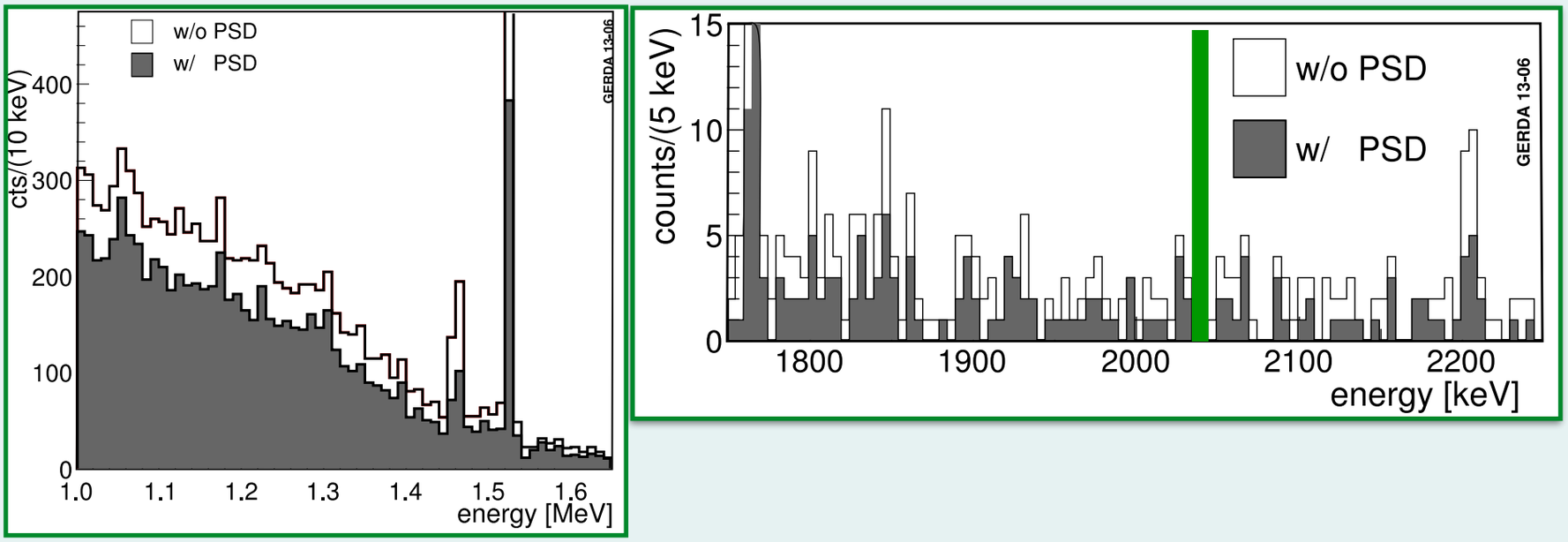


- Semi-coaxial detectors: Artificial Neural Network
- BEGe detectors: mono-parametric A/E method



Pulse Shape Discrimination Efficiencies

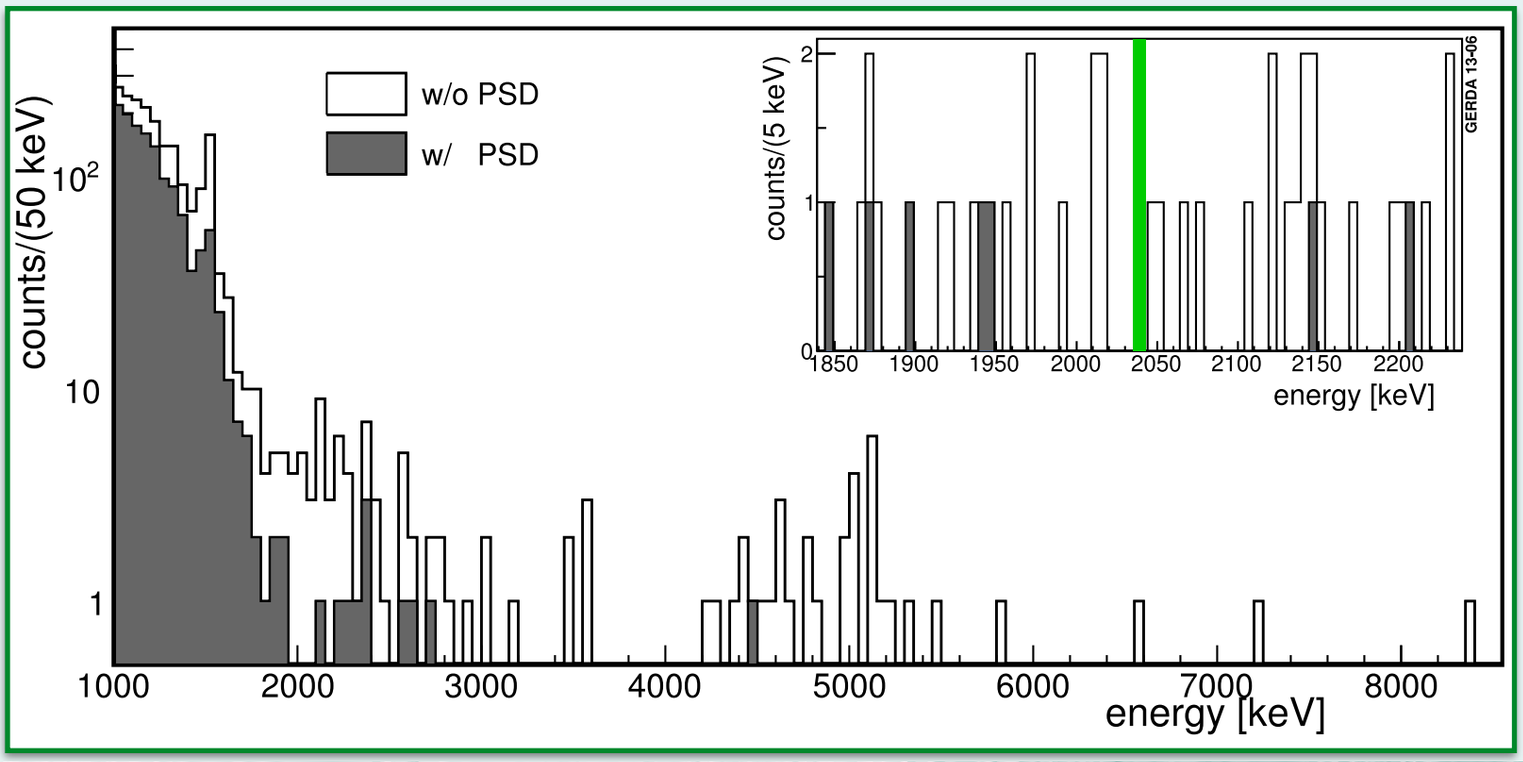
Semi-coaxial



Semi-coaxial

0νββ acceptance: 90_{-9}^{+5}%
BG rejection at Q_{bb}: ~45%
2νββ acceptance: 85±2%

BEGe

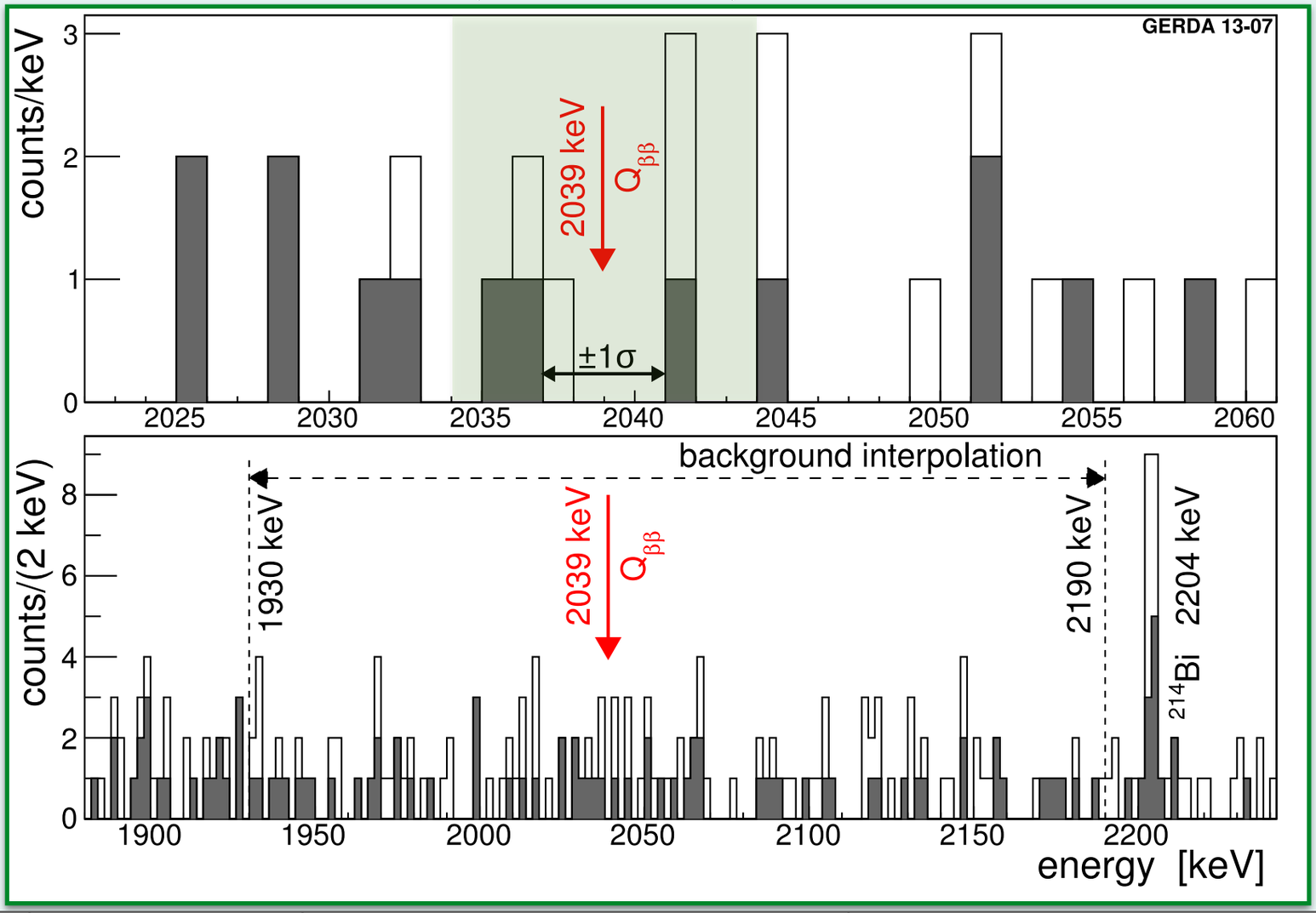


BEGe

0νββ acceptance: 92±2%
BG rejection at Q_{bb}: 80%
2νββ acceptance: 91±5%

Eur. Phys. J. C (2013) 73:2583

Phase I 0νββ results: unblinding

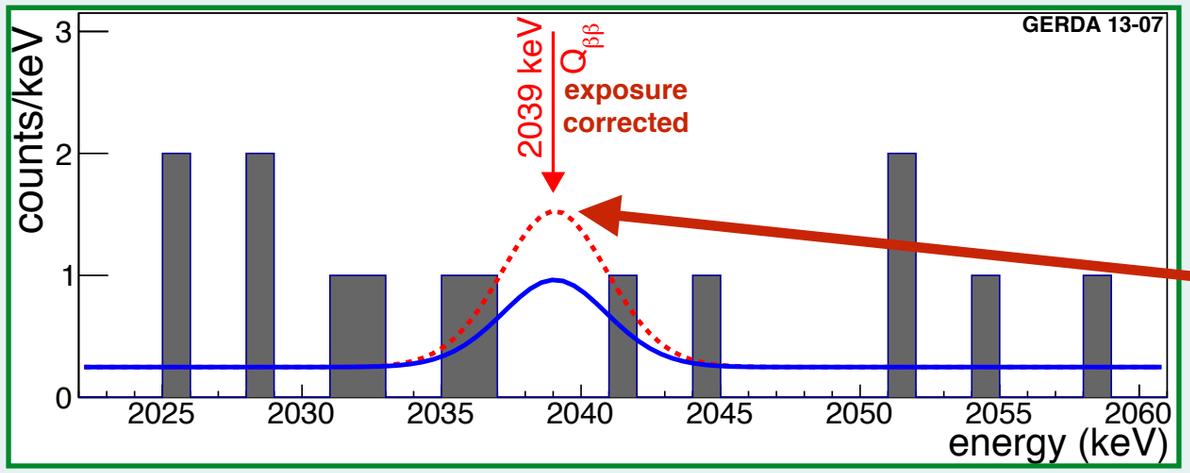


PRL 111, 122503 (2013)

before PSD
after PSD

dataset	exposure [kg yr]	background 10E-2 cts/(keV kg yr)		expected cts (Qbb ± 5 keV)		observed cts (Qbb ± 5 keV)	
golden	17.3	1.8	1.1	3.3	2.0	5	2
silver	1.3	6.3	3.0	0.8	0.4	1	1
BEGe	2.4	4.2	0.5	1.0	0.1	1	0

Phase I 0νββ results: $T_{1/2}$ limit



Frequentist analysis (baseline)

- profile likelihood fit to 3 datasets with common $1/T_{1/2}$
- best fit $N^{0\nu} = 0$ cts
- $N^{0\nu} < 3.5$ cts (90% C.L.)
- **$T_{1/2} > 2.1 \times 10^{25}$ yr (90% C.L.)**
- median sensitivity for no signal (MC)
  $T_{1/2} > 2.4 \times 10^{25}$ yr (90% C.L.)

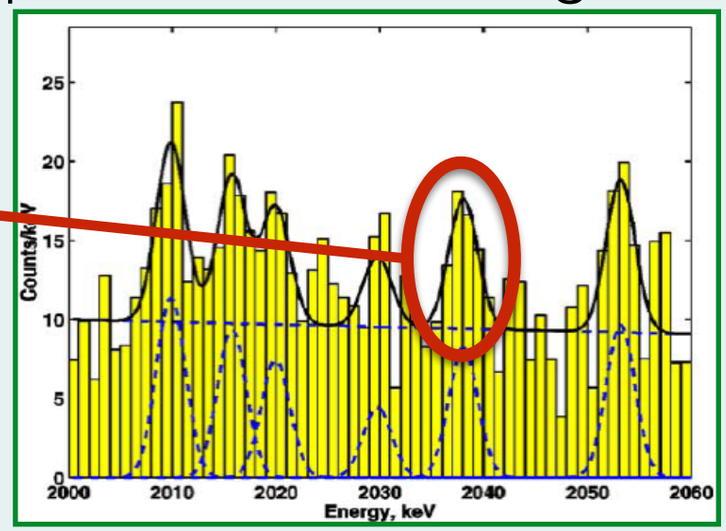
Bayesian analysis

- flat prior on $1/T_{1/2}$ in $(0, 10^{-24})$ yr^{-1} range
- best fit $N^{0\nu} = 0$ cts
- $N^{0\nu} < 4.0$ cts (90% C.I.)
- **$T_{1/2} > 1.9 \times 10^{25}$ yr (90% C.I.)**
- median sensitivity for no signal (MC)
  $T_{1/2} > 2.0 \times 10^{25}$ yr (90% C.I.)

Combined GERDA + IGEX + HdM

- **$T_{1/2} > 3.0 \times 10^{25}$ yr (90% C.L.)**

comparison with the signal claim



Hypothesis test:

H_0 : background only
expected cts: 2.0±0.3

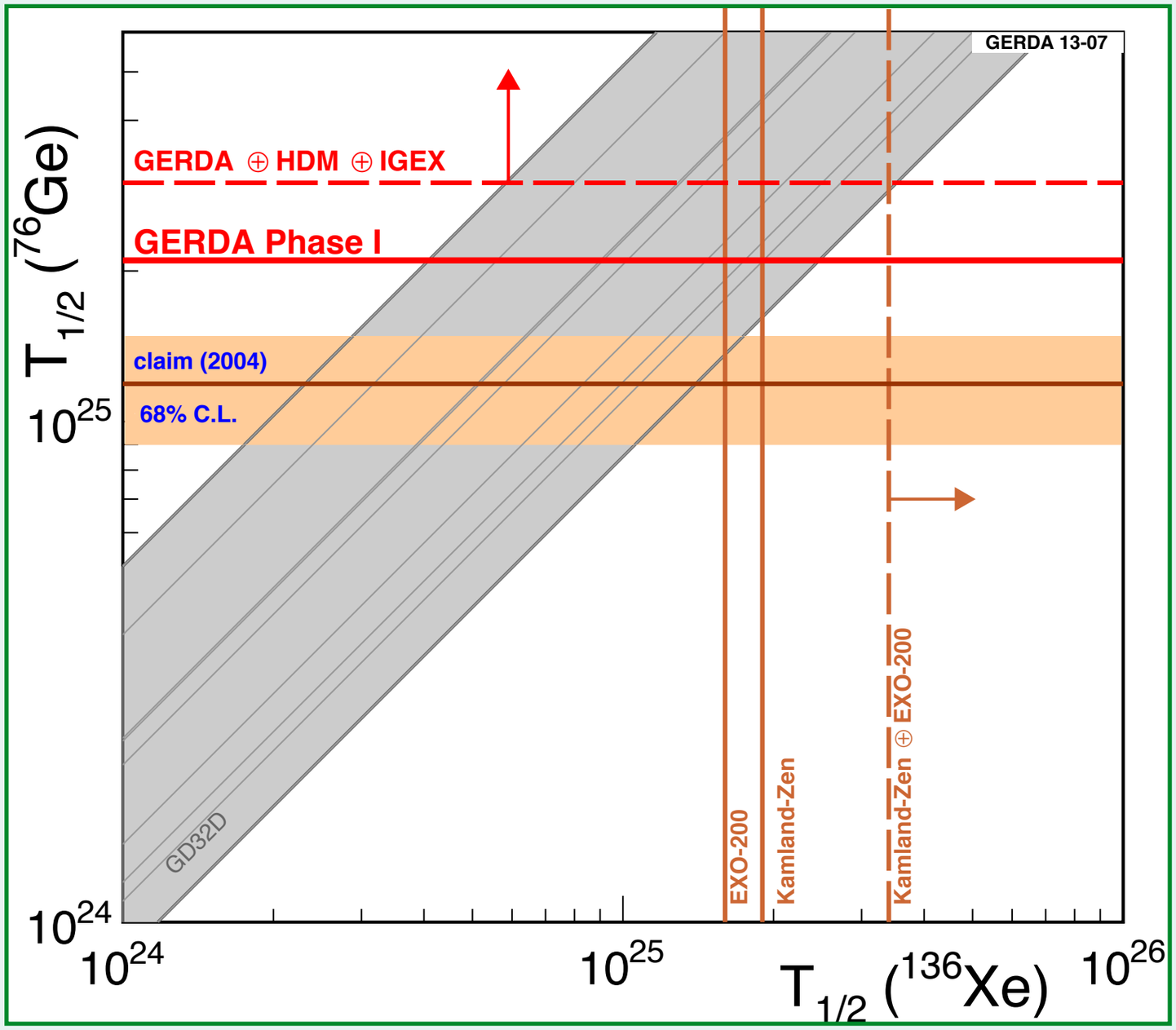
H_1 : claimed signal ($T_{1/2} = 1.19 \times 10^{25}$ yr) +bg
expected cts: 5.9±1.4

Observed cts: 3

- Frequentist p-value $P(N^{0\nu}=0 | H_1) = 0.01$
- Bayes factor $P(H_1 | H_0) = 2.4 \times 10^{-2}$
- Bayes factor $P(H_1 | H_0) = 2.0 \times 10^{-4}$ (combined)

long standing claim disfavoured

Comparison with ^{136}Xe experiments



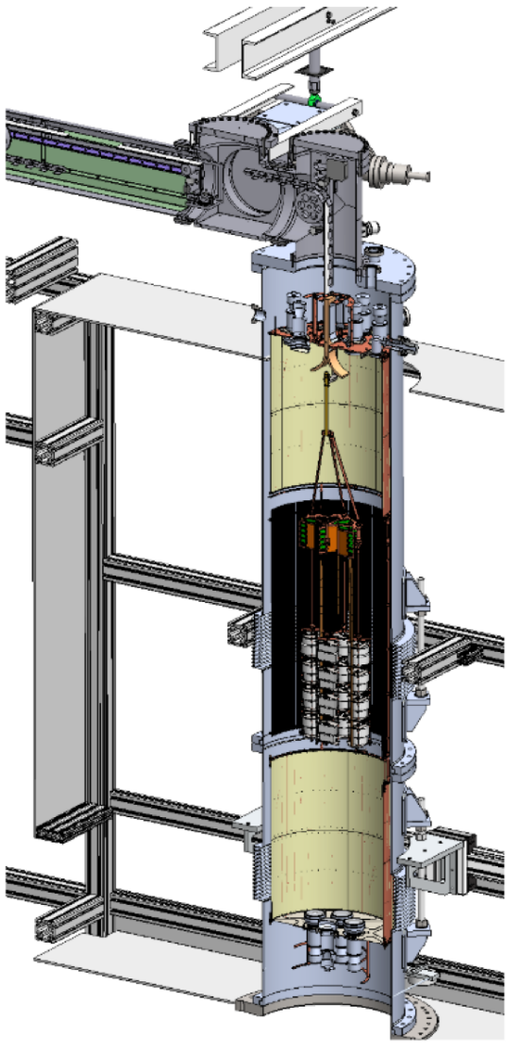
- GERDA provides model-independent test of the signal claim
- comparison with ^{136}Xe experiments:
  - assuming leading mechanism is exchange of light Majorana ν
  - matrix element computations (model dependent)
    Phys. Rev. D 88, 091301 (2013)

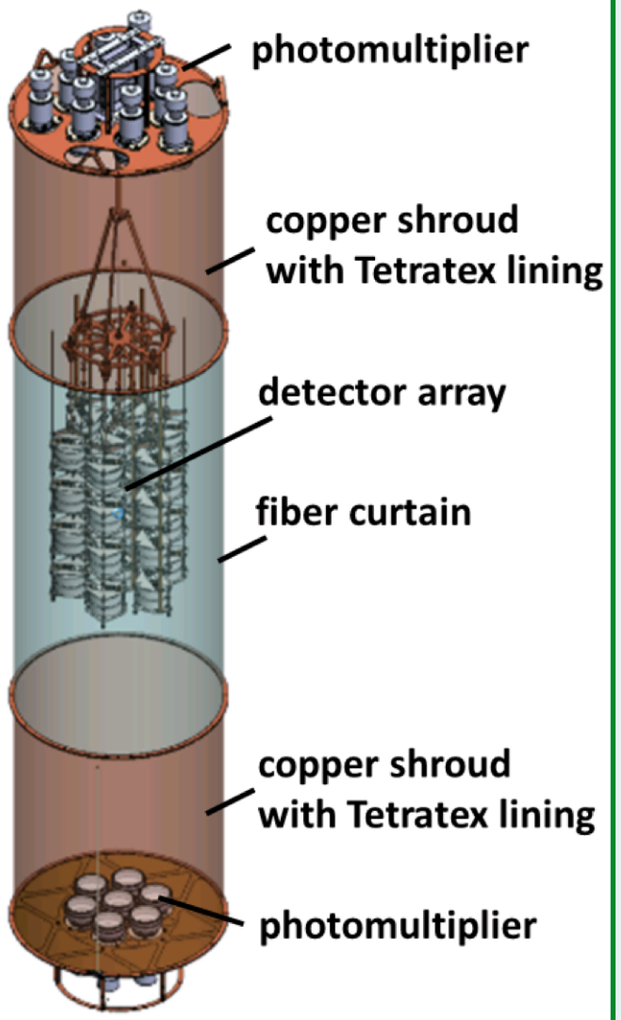
combined GERDA+EXO+KamLAND-Zen

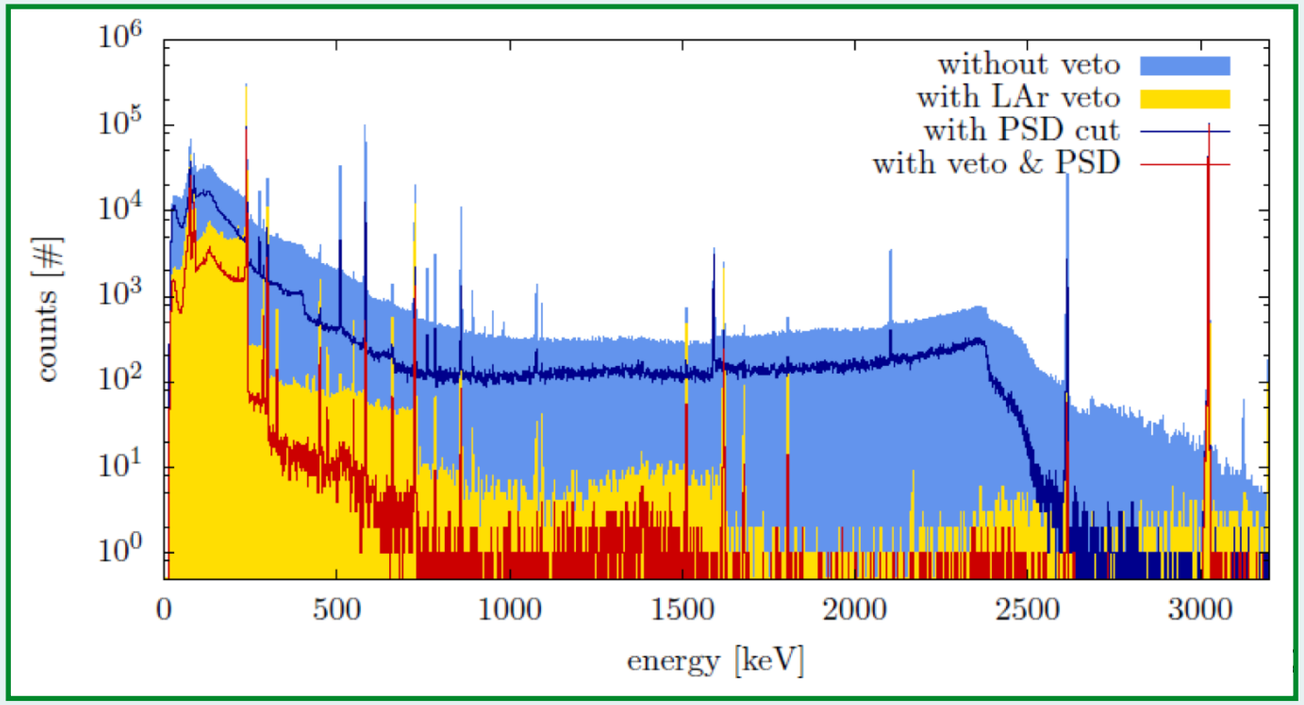
Bayes factor $P(H_1)/P(H_0) = 2.2\times10^{-3}$

(computed for smallest NME ratio Xe/Ge)

Phase II lock system and LAr instrumentation







new Lock system

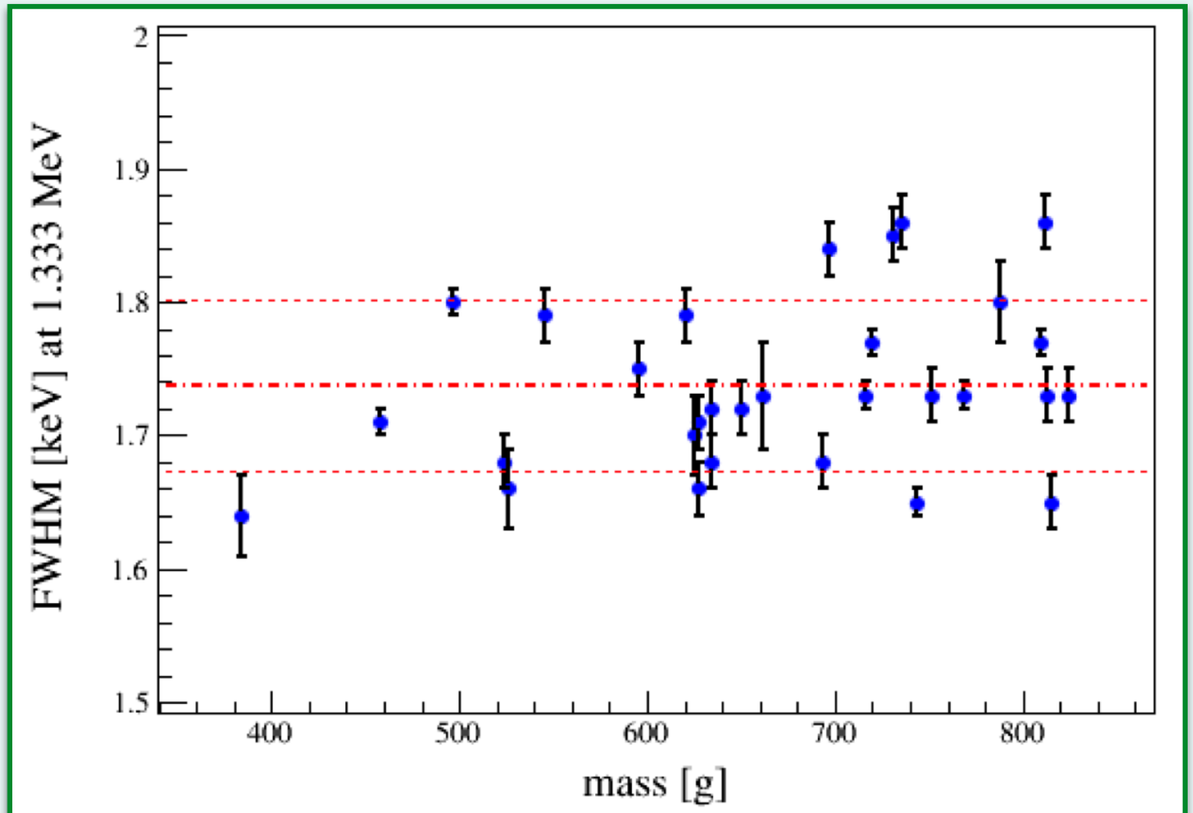
- size of detector array increased to 7 strings
- LAr instrumentation surrounding the array

Liquid Argon scintillation as background veto

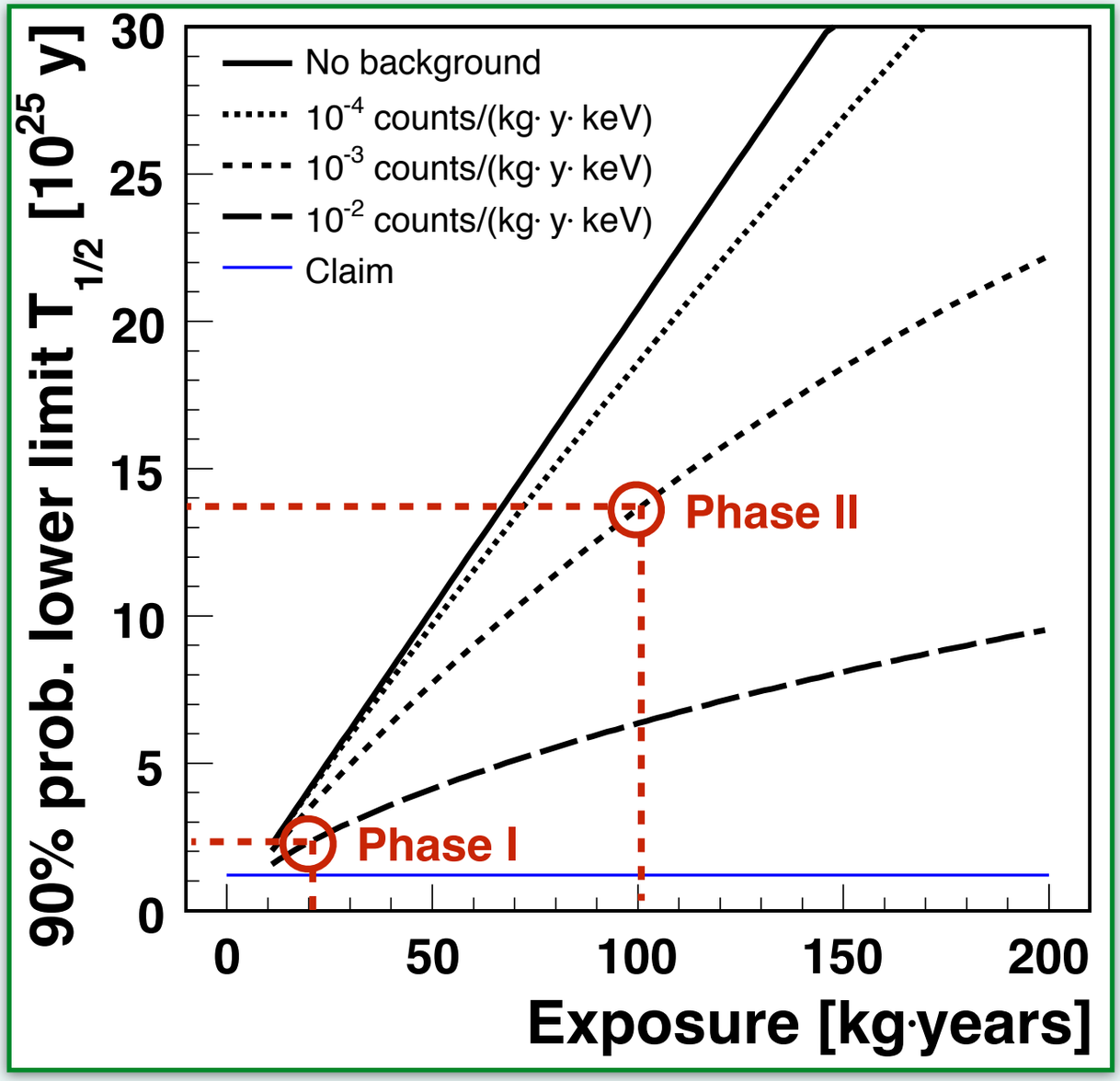
- PMT arrays on top and bottom
- Si-photomultipliers coupled to WLS fibers

Pulse shape analysis and LAr veto measured a suppression factor of $(5.2\pm1.3)\times10^3$ at Q_{bb} for close ^{228}Th

New BEGe detectors and Phase II sensitivity



- 30 new BEGe detectors for Phase II
  stored in LNGS (20kg)
- Detector Modules:
  Significant amount of copper and PTFE replaced by intrinsically radio-pure silicon
- energy resolution (vacuum test) at 1.3MeV:
  <1.9 keV (FWHM)
- A/E PSD
  robust, simple, well-understood
- low BI due to cosmogenic activation (^{60}Co, ^{68}Ge):
  <10^{-4} cts/(keV kg yr)



Phys. Rev. D75, 092003 (2006)

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

Summary and Outlook

- <u>GERDA Phase I design goals reached</u>
  - exposure of 21.6 kg yr
  - background index at Q_{bb} after PSD: 0.01 cts/(keV kg yr)
  - no 0νββ signal observed
    long standing claim claim strongly disfavoured
  - new limit on 0νββ half-life
    $T_{1/2} > 2.1 \times 10^{25}$ yr (90% C.L.)

- <u>GERDA Phase II transition ongoing</u>
  - additional 20kg of detector mass
  - new custom-made BEGe detectors with enhanced PSD
  - Liquid Argon instrumentation
  - background target 10^{-3} cts/(keV kg yr)
  - explore 0νββ $T_{1/2}$ values in the 10^{26} yr range