# GERDA Collaboration: the first results on neutrinoless double beta decay of 76Ge from Phase I

**Kornoukhov Vasily (ITEP&INR RAS)**
**for the GERDA collaboration**

**International Workshop on Particle Astrophysics**
**Samcheok, January 21st, 2014**

# The GERDA collaboration

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**18 institutions**
**6 countries**


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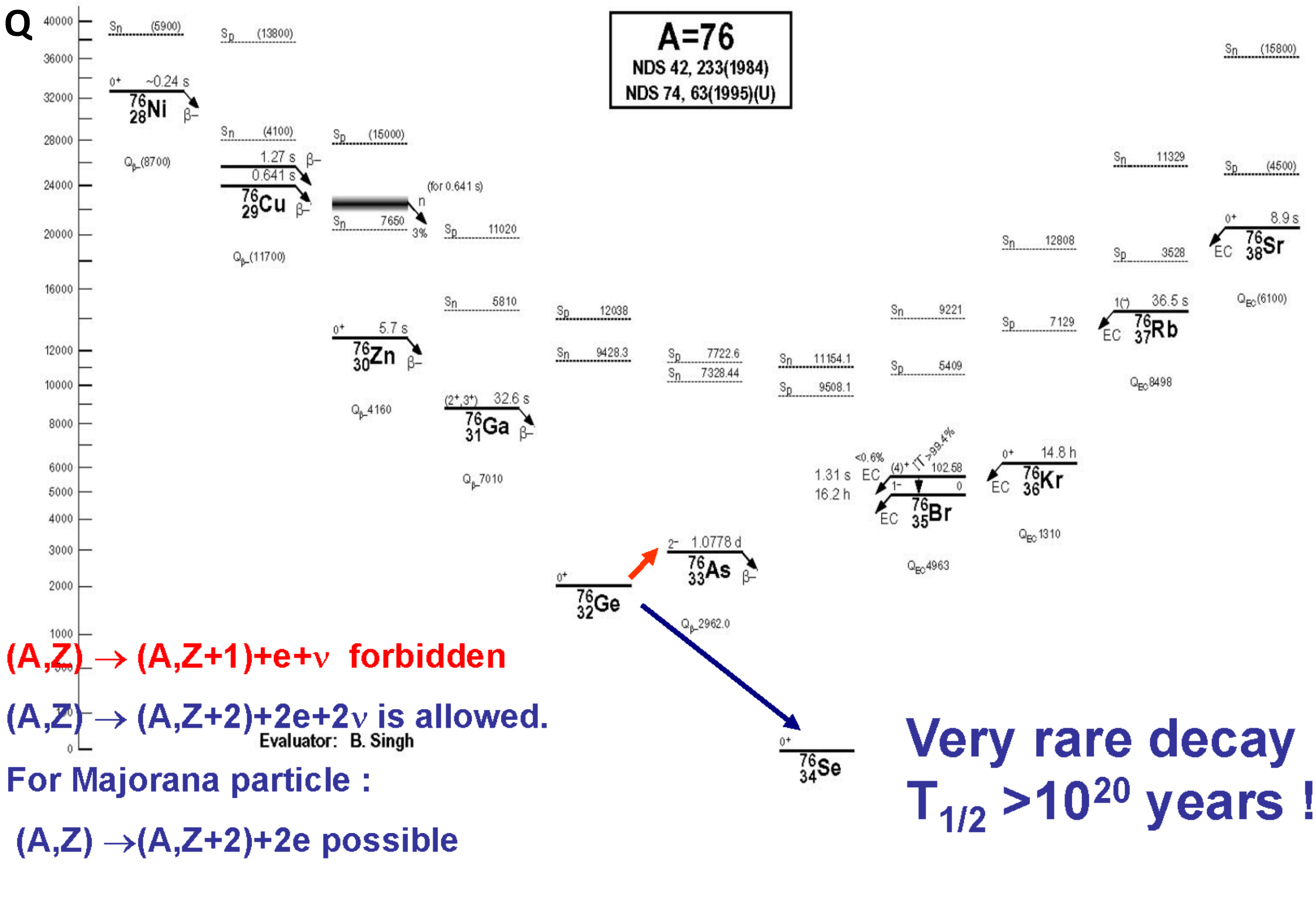
# Isobar curve A = 76 & double beta decay

Maria Goeppert-Mayer (1935)




$(A,Z) \to (A,Z+1)+e+\nu$ forbidden

$(A,Z) \to (A,Z+2)+2e+2\nu$ is allowed.

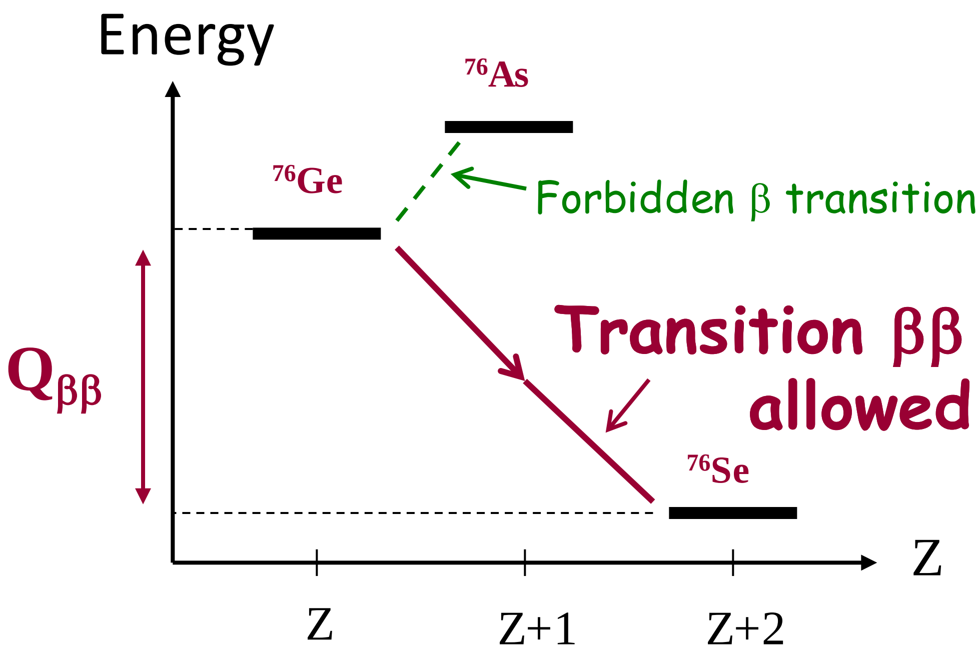
For Majorana particle :

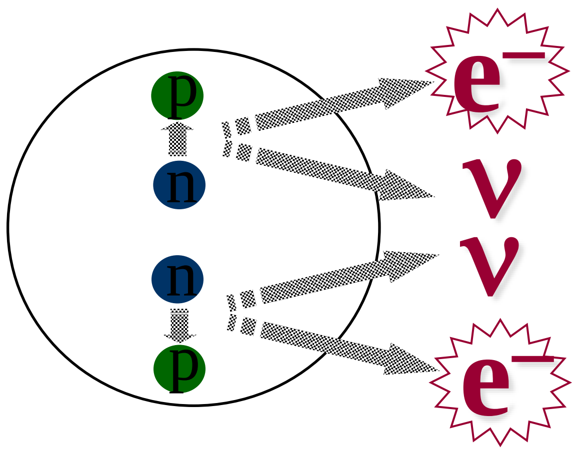
$(A,Z) \to (A,Z+2)+2e$ possible

# Allowed double beta decay....

For some nuclei single β decay is impossible

But 2β decay is allowed

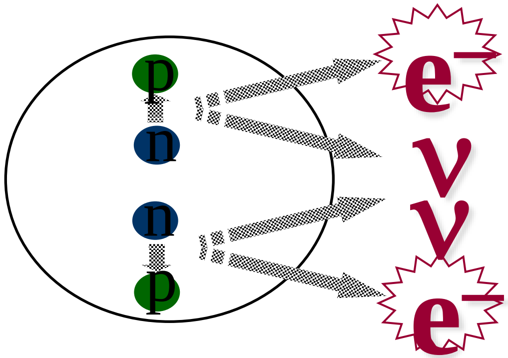


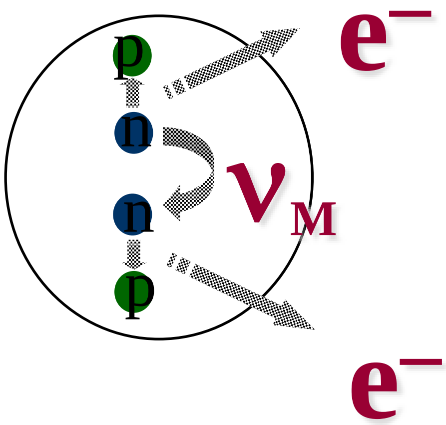



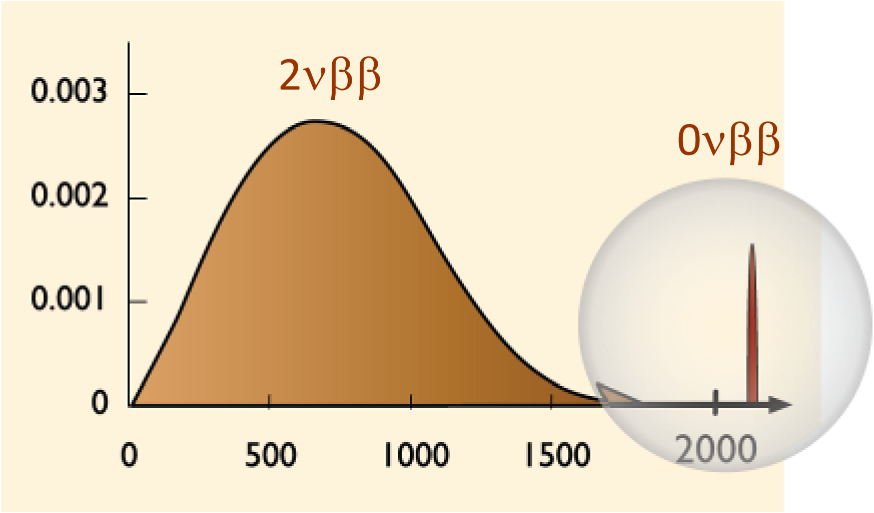
# Ettore Majorana (1937): the neutrino its own particle (?)

In 1937 Ettore Majorana: neutrino is its own anti-prticle

➡ If neutrino is Majorana: ββ **without neutrino emission**



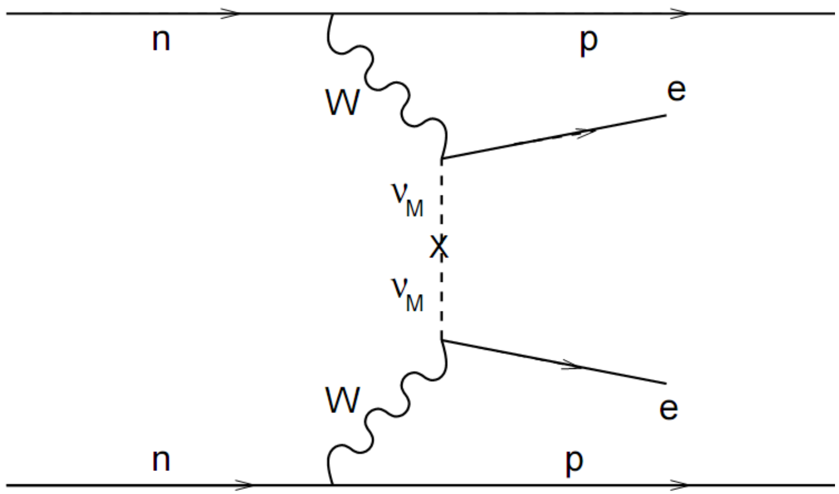




$^{76}Ge$

Q = 2039 keV

# 0νββ decay and neutrino mass

**(*Z*, *A*) → (*Z* + 2, *A*) + 2*e*−**




*L* = 2 = Prohibited by SM
Light Majorana neutrino exchange
*Q* = *Mi* − *Mf* − 2*me*

## Expected decay rate:

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2 \,\langle m_{ee} \rangle^2$$

Phase space integral — Nuclear matrix element

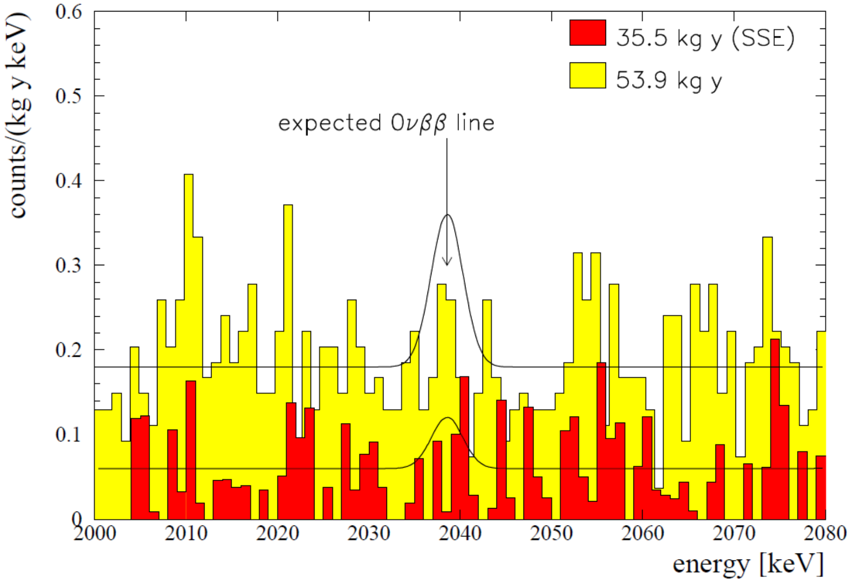
$$\langle m_{ee} \rangle = \left| \sum_i U_{ei}^2 m_i \right|$$ Effective neutrino mass

$U_{ei}$ Elements of (complex) PMNS mixing matrix

Discovery of 0νββ decay would imply:

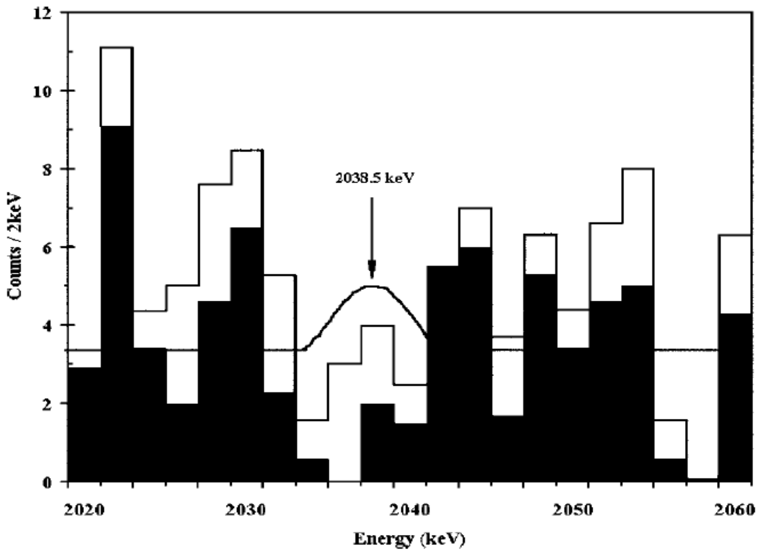
- lepton number is violated ΔL = 2
- ν's have Majorana character
- physics beyond the standard model

# $^{76}$Ge 0νββ search with HPGe detectors




Heidelberg-Moscow
(H.V. Klapdor-Kleingrothaus et al.)
(Eur. Phys. J. A 12, 147-154 (2001)):

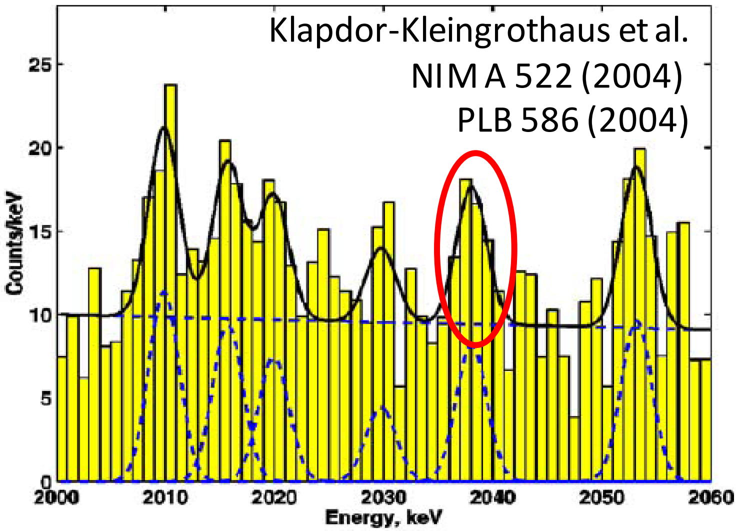
53.9 kg y: $T_{1/2}^{0\nu} > 1.3 \times 10^{25}$ yr (90% C.L.)
35.5 kg y: $T_{1/2}^{0\nu} > 1.9 \times 10^{25}$ yr (90% C.L.)

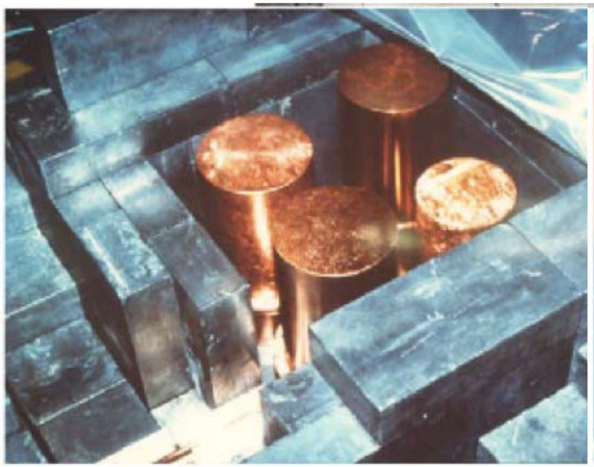



IGEX
(Aalseth et al.)
Phys. Rev. D 65 (2002) 092007

8.8 kg y: $T_{1/2}^{0\nu} > 1.6 \times 10^{25}$ yr (90%C.L.)

# $^{76}$Ge 0νββ search: the claim



Klapdor-Kleingrothaus et al., NIM A 522 (2004), PLB 586 (2004):

- 71.7 kg year - Bgd 0.17 evt/(kg yr keV)
- 28.75 ± 6.87 events (bgd: ~ 60)
- Claim: 4.2σ evidence for 0νββ
- reported $T^{0\nu}_{1/2} = \left(1.19^{+0.37}_{-0.23}\right) \cdot 10^{25}$ yr

N.B. Half-life $T_{1/2}{}^{0\nu}$ = 2.23 x$10^{25}$ yr after PSD analysis (**Mod. Phys. Lett. A 21, 1547 (2006)**) is not considered because:

- reported half-life can be reconstructed only (Ref. 1) with $\varepsilon_{psd}$ = 1 (previous similar analysis $\varepsilon_{psd} \approx 0.6$)
- $\varepsilon_{fep}$ = 1 (also in NIM A 522, PLB 586 (2004))

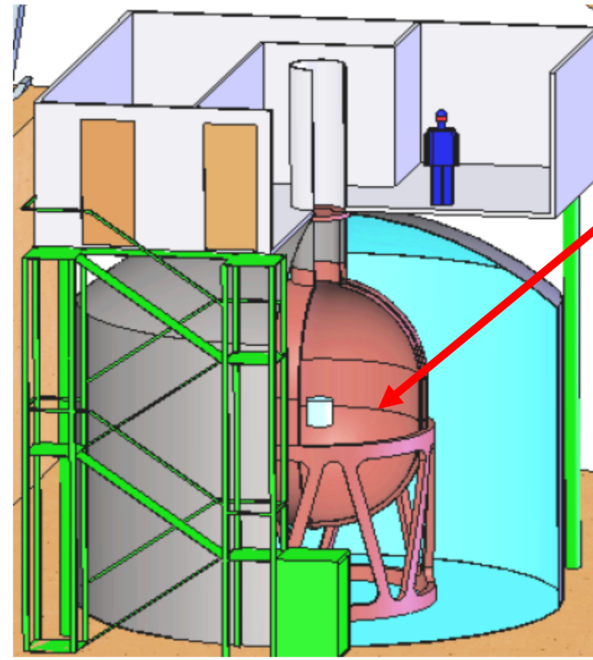
(GERDA value for same detectors: $\varepsilon_{fep}$ = 0.9)

*1) B. Schwingenheuer in Ann. Phys. 525, 269*

# The GERDA searches for 0νββ-decay $^{76}Ge \rightarrow {}^{76}Se + 2e^-$

- Idea by Gerd Heusser 1995: naked HPGe detectors
- GERDA proposal 2004
- construction 2006-2010
- commissioning 2010-11
- physics data Phase I: 2011-13

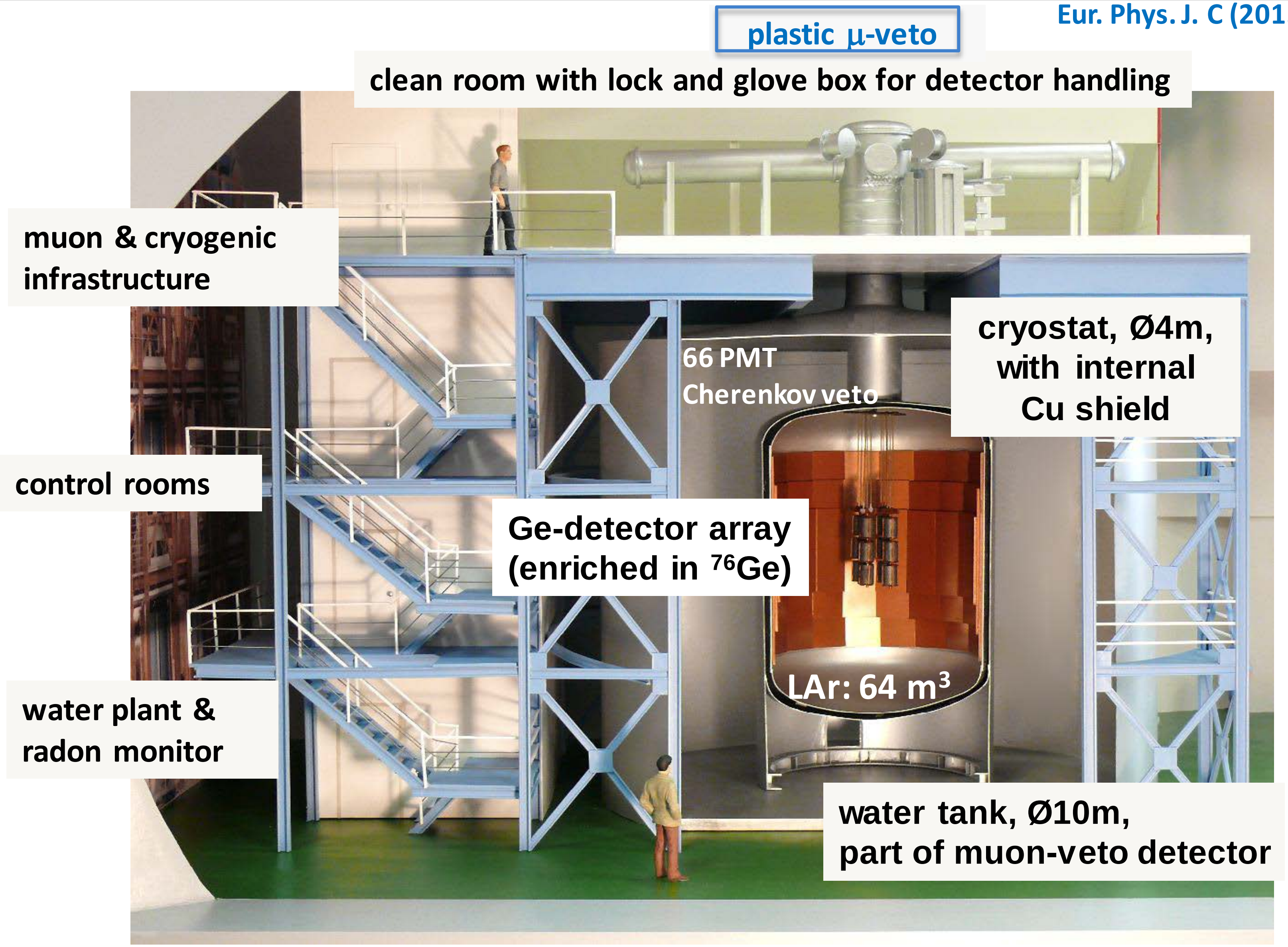

Hall A LNGS
3800 m.w.e.
Muons flux suppression
$10^6$ times



- 'Bare' $^{enr}$Ge array in liquid argon
- Shield: high-purity liquid Argon / $H_2O$
- Phase I: 18 kg (HdM/IGEX)
- Phase II: add ~20 kg new enriched detectors

# Artists view of the GERDA detector

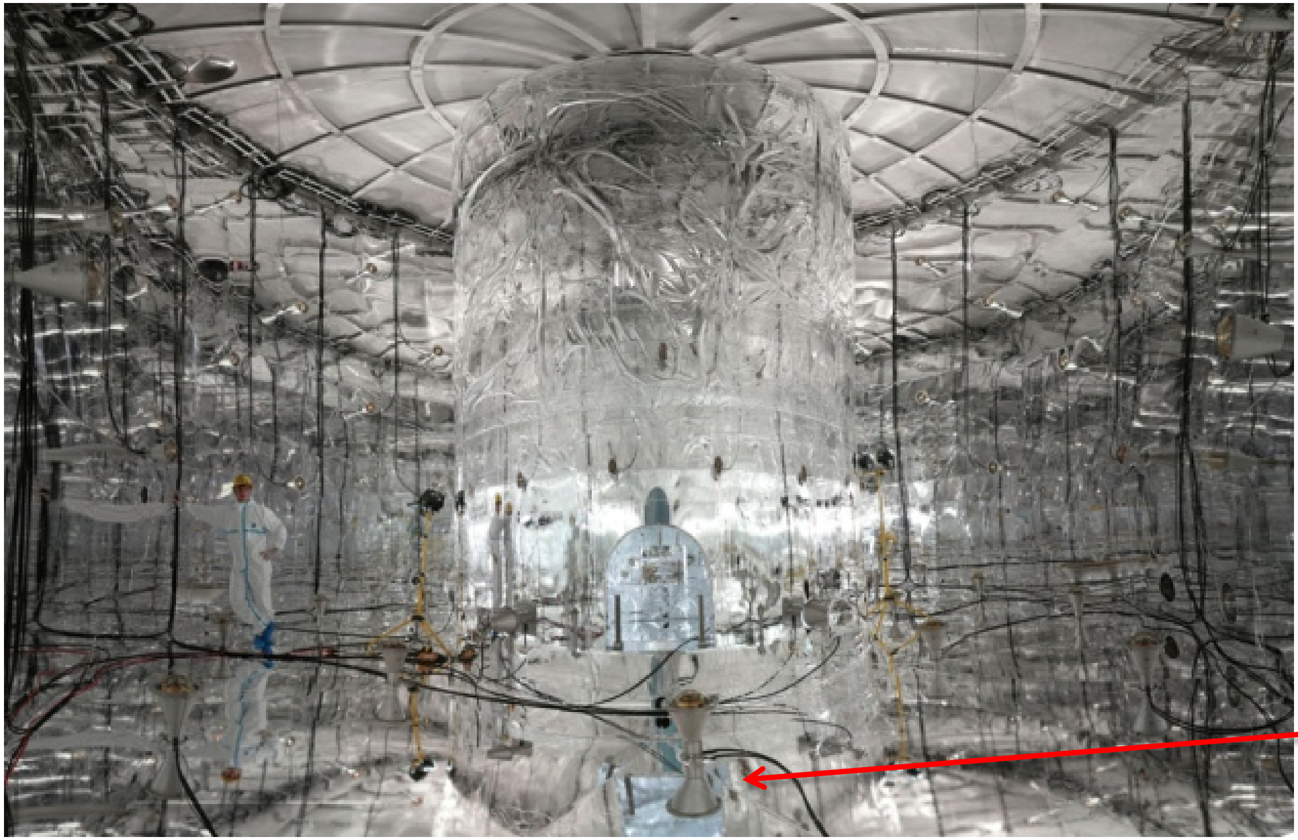
Eur. Phys. J. C (2013) 73:2330



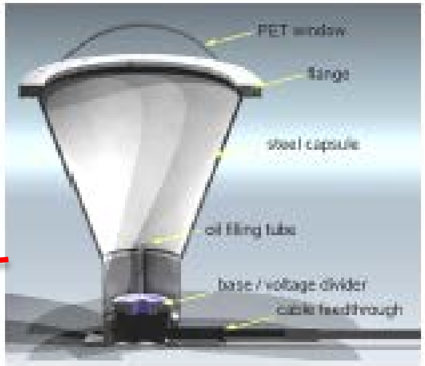
# Water Cherenkov detector and plastic scintillator muon veto

Eur. Phys. J. C (2013) 73:2330
[arXiv:1212.4067](arXiv:1212.4067)

**Plastic μ-veto →**
**12 panels x 3 layers**
**$S = 4 \times 3\ m^2$**



**66 PMT (8")**
**(0,5% of the surface)**
**VM2000 reflective foil**
**Overall muon reject efficiency**
**$\varepsilon = 0{,}991$**
**$BI_{\mu} < 10^{-3}$ cts/keV·kg·yr**



# Phase I detectors: semi-coaxial detectors

Eur. Phys. J. C (2013) 73:2330
arXiv:1212.4067


- HdM & IGEX diodes reprocessed at Canberra, Olen
- Long term stability in LAr w/o passivation layer
- Energy resolution in LAr: ~2.5 keV (FWHM) @1.3 MeV

8 diodes (from HdM, IGEX):

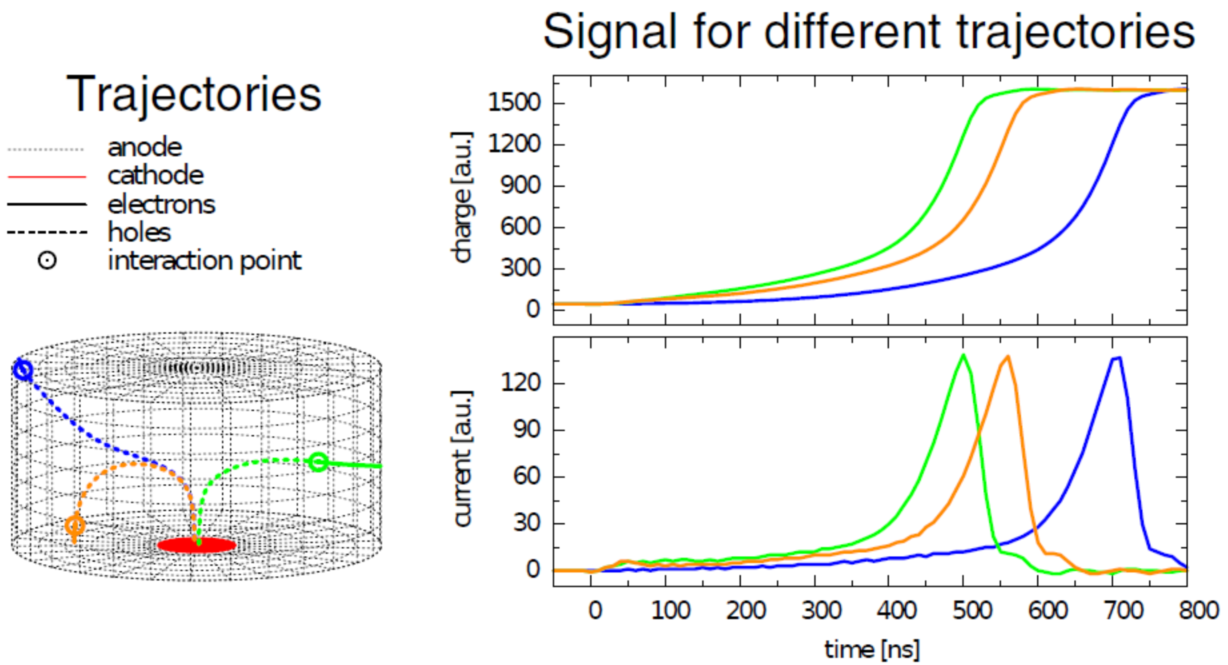
- Enriched 86% in $^{76}$Ge
- **Total mass 17.66 kg**

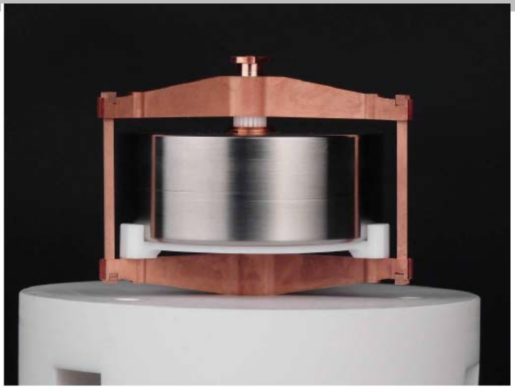
65 um Cu cylinder ("mini-shroud to Shield E-field")

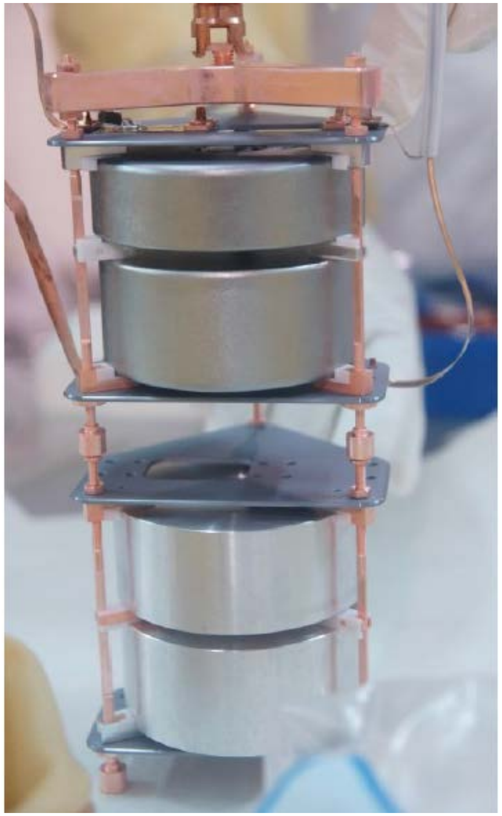
6 diodes from Genius-TF:

- $^{nat}$Ge
- Total mass: 15.60 kg

# BeGe detectors for Phase II



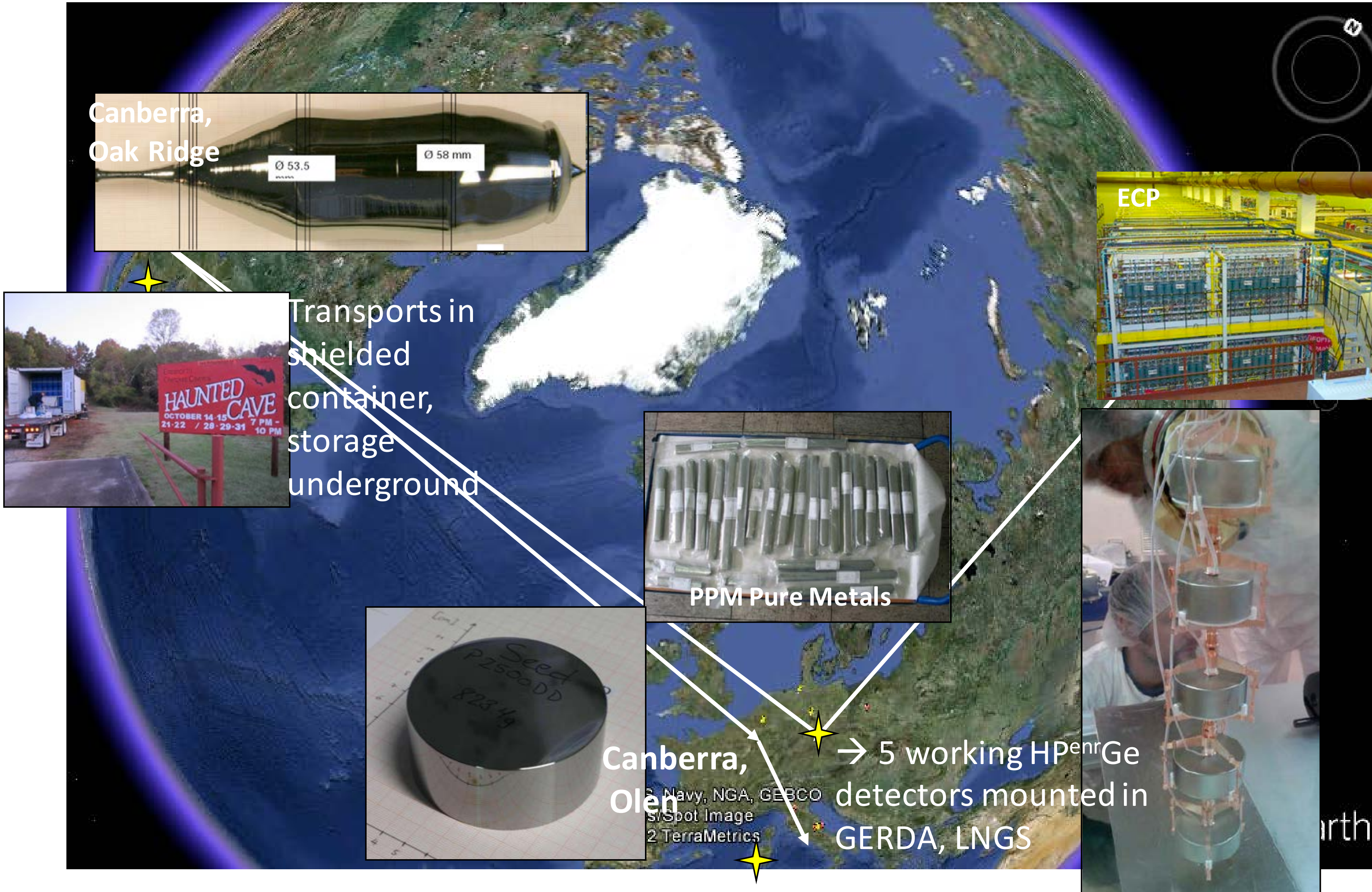





- BeGe: Broad-Energy Germanium Detector (Canberra)
- No bore-hole, small contact:
  - Small capacitance, higher energy resolution
  - Strong weighting field
- Charges from different points → signals at different times

**5 BEGe's (3,63 kg) inserted in GERDA in July 2012**

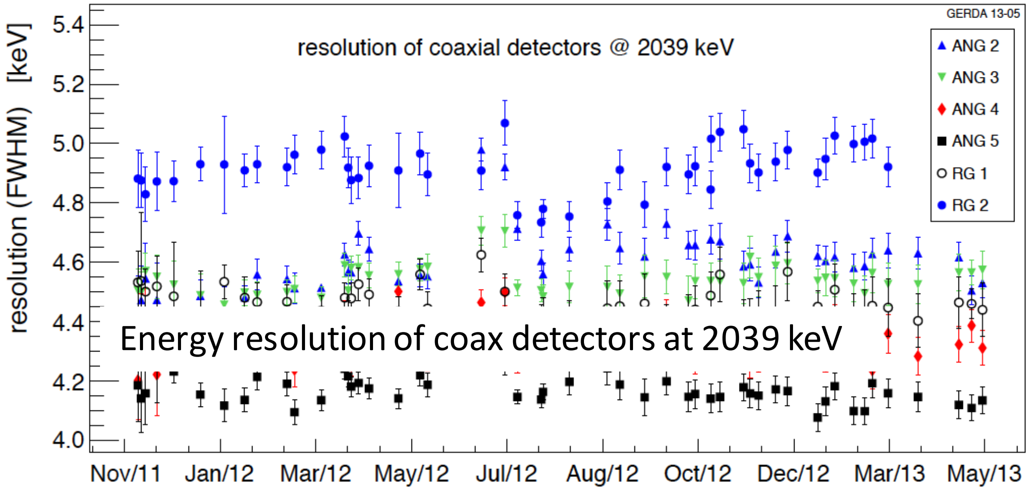
# Production of $^{enr}$Ge Phase II detectors



# Energy calibration & data processing of HPGe detectors

- weekly calibrated spectra with $^{228}$Th sources and pulser with 0.05 Hz frequency
- data useful for monitoring of <u>resolution</u> and <u>stability</u> over time
- FWHM at $Q_{\beta\beta}$ is about 4.8 keV for Coaxials (0.23%) and 3.2 keV (0.16%) for BEGes

arXiv 1212.4067




Energy resolution of coax detectors at 2039 keV

Summing all runs:

Peak position stability of 2614.5 keV calibration line: coax: 1.5 keV / BEGe: 1.0 keV (FWHM)

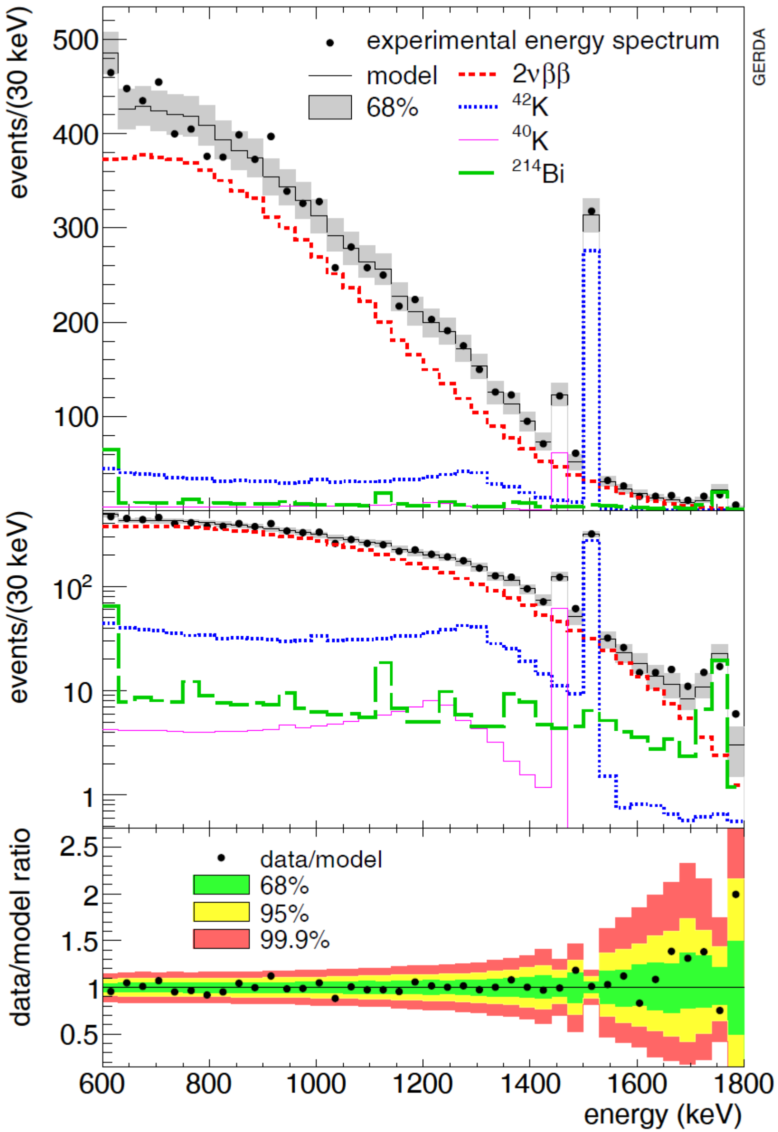
arXiv:1306.5084

| detector | FWHM [keV] | detector | FWHM [keV] |
|---|---|---|---|
| *SUM-coax* | | *SUM-bege* | |
| ANG 2 | 5.8 (3) | GD32B | 2.6 (1) |
| ANG 3 | 4.5 (1) | GD32C | 2.6 (1) |
| ANG 4 | 4.9 (3) | GD32D | 3.7 (5) |
| ANG 5 | 4.2 (1) | GD35B | 4.0 (1) |
| RG 1 | 4.5 (3) | | |
| RG 2 | 4.9 (3) | | |
| mean coax | 4.8 (2) | mean BEGe | 3.2 (2) |

**Data processing**: diode → amplifier → FADC → digital filter → energy, pulse shape,...

**Data selection**: anti coincidence + quality cuts + pulse shape discrimination (total fraction of accepted events = 65%)

# Measurement of $T^{2\nu}_{1/2}$ ($^{76}Ge$)

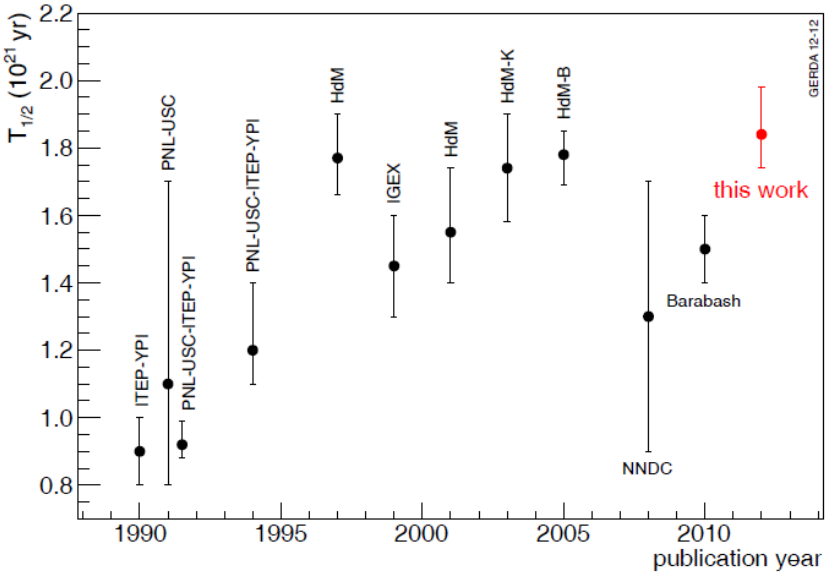



IOP PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. **40** (2013) 035110 (13pp) doi:10.1088/0954-3899/40/3/035110

**Measurement of the half-life of the two-neutrino double beta decay of $^{76}$Ge with the GERDA experiment** (with 5.04 kg yr exposure)

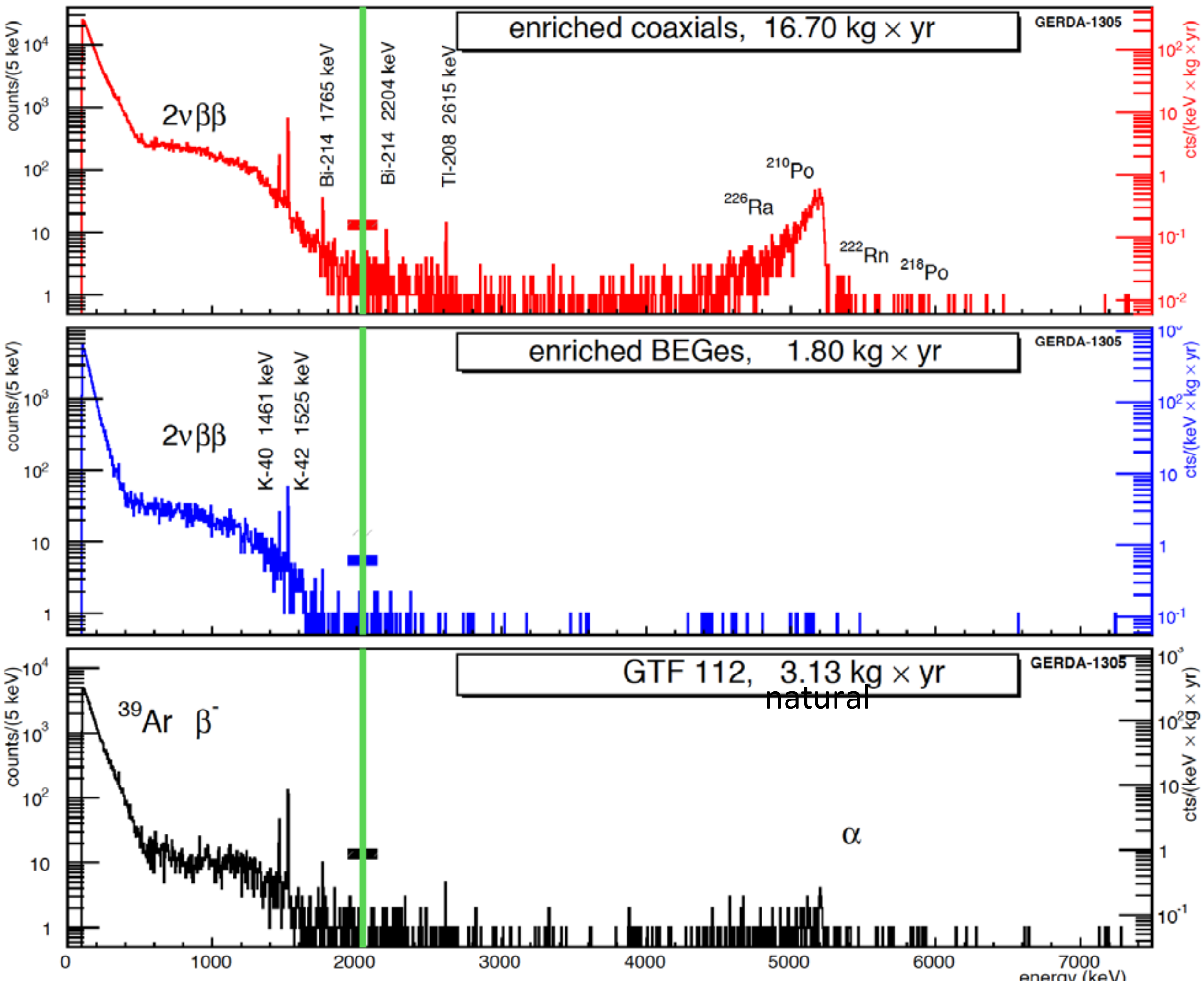
$T^{2\nu}_{1/2}(^{76}Ge) = (1.84^{+0.14}_{-0.10}) \cdot 10^{21}$ yr




LAB Talk of J. Phys. G Feb. 2013 issue:
http://iopscience.iop.org/0954-3899/labtalk-article/52398

# Physics energy spectra

arXiv:1306.5084




Blinding window
$Q_{\beta\beta}$+/-20 keV

**Phase I data split into 3 sets**

- **"golden coax" = 17.9 kg yr**
  **all semi-coax data but 4 weeks**
- **"silver coax" = 1.3 kg yr**
  **4 weeks when BEGe inserted**
- **"BEGe" = 2.4 kg yr**

**background level:**

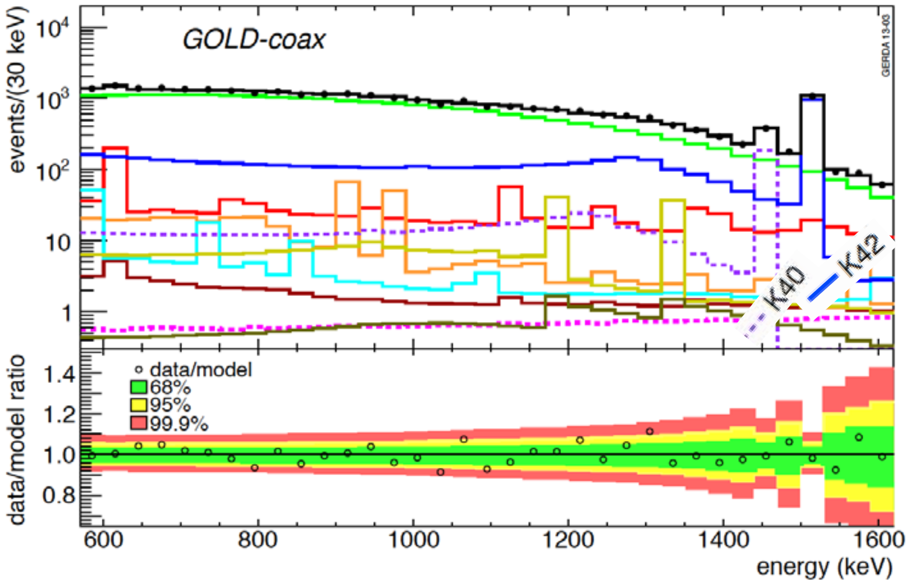
| | GERDA | HdM |
|---|---|---|
| 2615 keV [cts/(kg yr)] | 1,1±0,3 | |
| 1764 keV [cts/(kg yr)] | 3,3±0,5 | |
| avg@$Q_{\beta\beta}$ [cts/(kev kg yr)] | 0,018±0,002[1] | 0,17±0,05[2] |

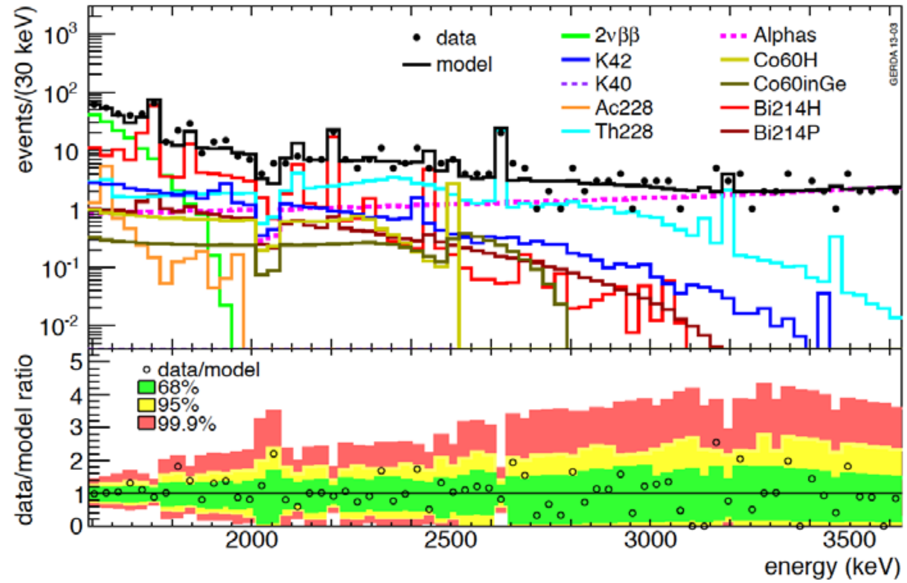
1 "golden coax" in 1930 – 2190 keV

2 1995-2003 data, 2000 – 2100 keV

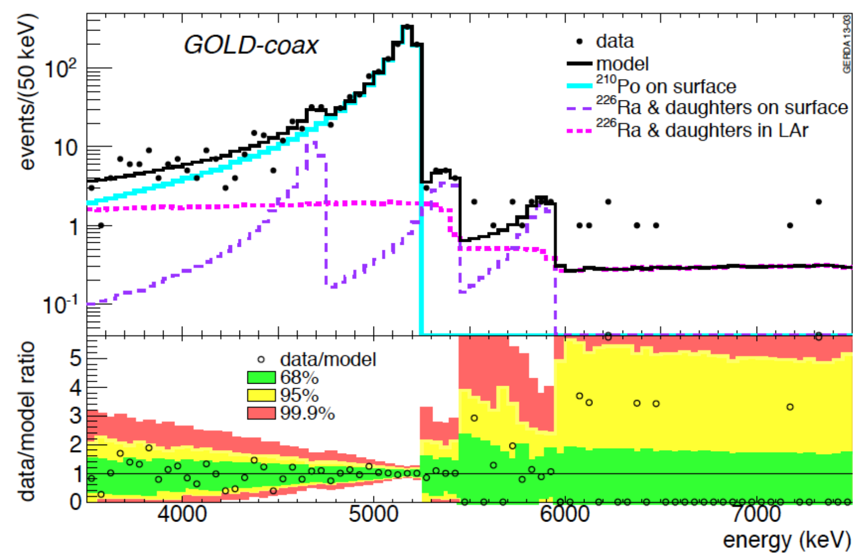
# Background model

arXiv:1306.5084



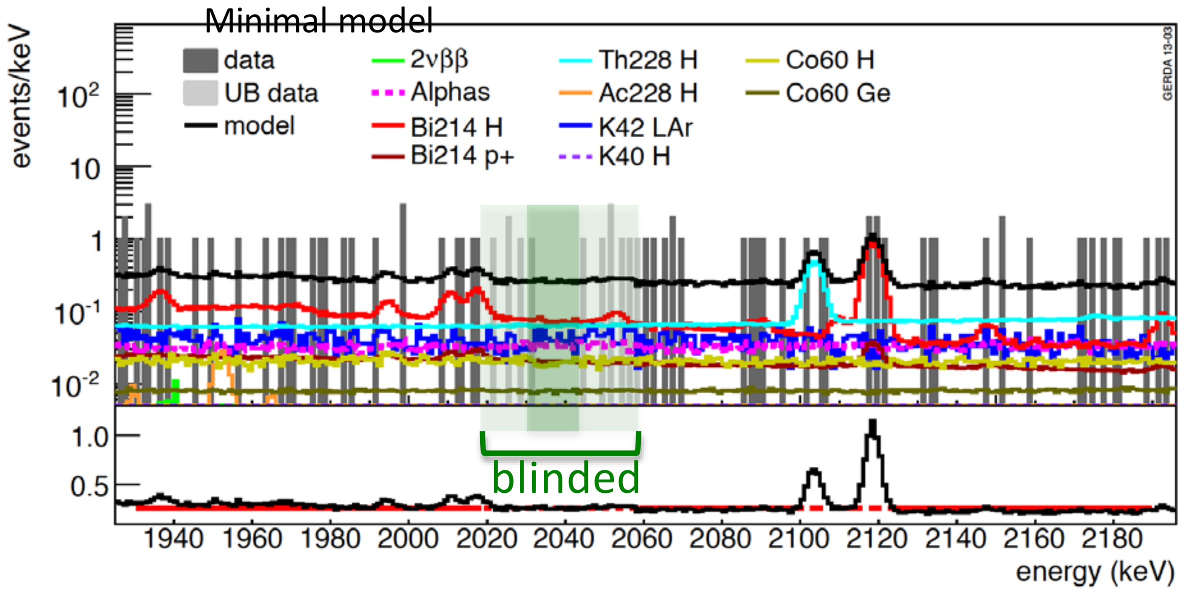

- simulate known & observed backgrounds
- fit combination of MC spectra to data in interval 570 keV – 7500 keV
→ relative contribution of backgrounds
- no unique determination

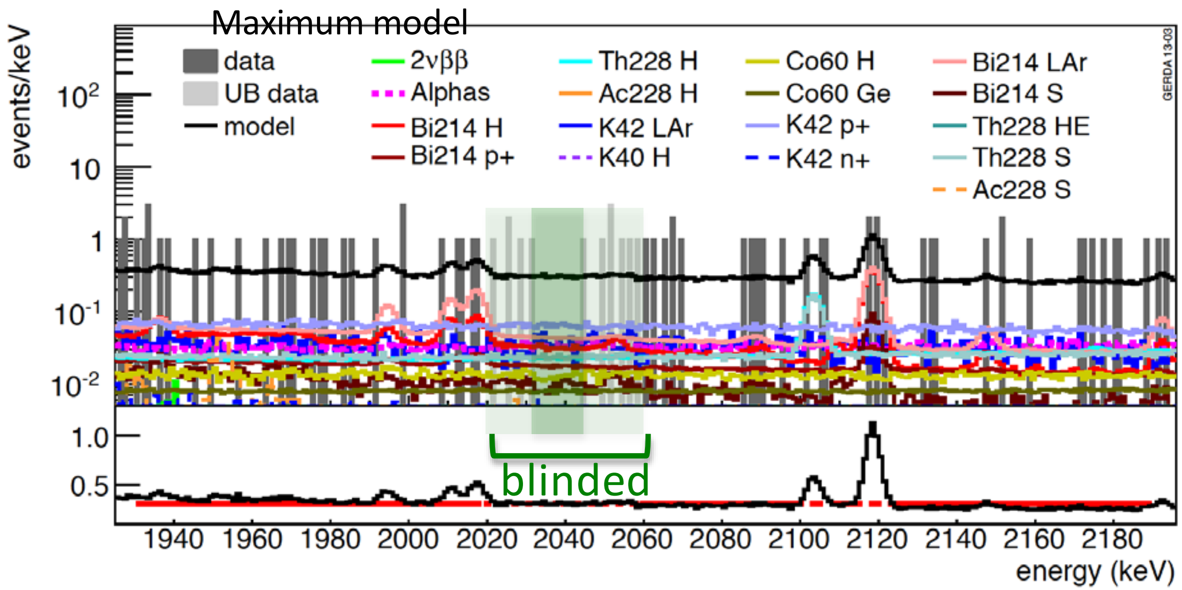



**"Close" background sources dominate:**
**$^{42}Ar$, $^{228}Th$ & $^{226}Ra$ in holder,**
**α on detector surface.**

# Physics run: background model and prediction of BI at $Q_{\beta\beta}$

arXiv:1306.5084




Background model:

- No background peak expected around $Q_{\beta\beta}$
- Spectrum can be modeled with flat background (red line) in 1930-2190 keV excluding known peaks at 2104 and 2119 keV
- Background index (BI) at $Q_{\beta\beta}$ (17.6-23.8) $10^{-3}$ cts/(keV kg yr) depending on assumptions for location of sources
- Statistical uncertainty of BI from interpolation coincides numerically with systematic uncertainty from model
- Prediction for 30 keV BW:
  Min./Max Mod: 8.2-9.1 / 9.7-11.1
  observed.: 13

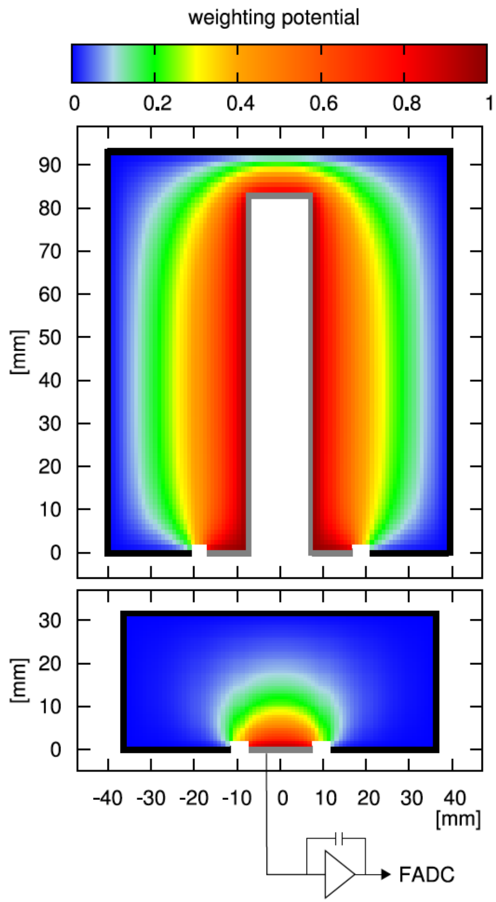
➔ linear fit with flat background 1930-2190 keV excluding peaks

# Pulse shape discrimination

EPJC 73 (2013) 2583

Classification of (0νββ) signal-like (SSE) or background-like (MSE, p+) events

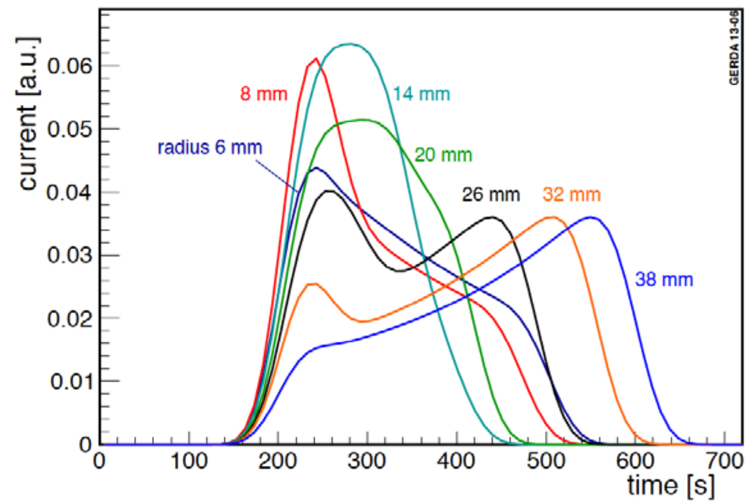
Weighting potential for coax and BEGe detectors are different

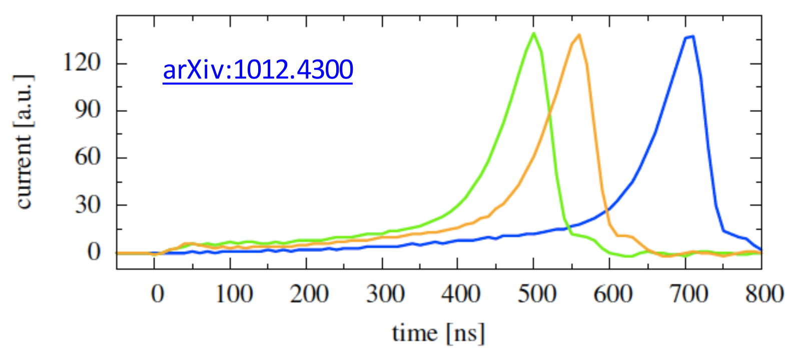



Coax

BEGe

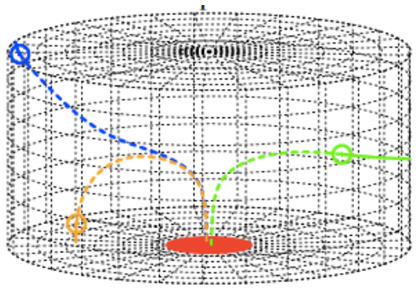
Current pulses of simulated SSE signals

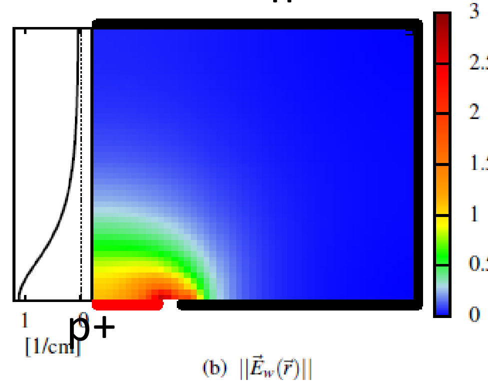


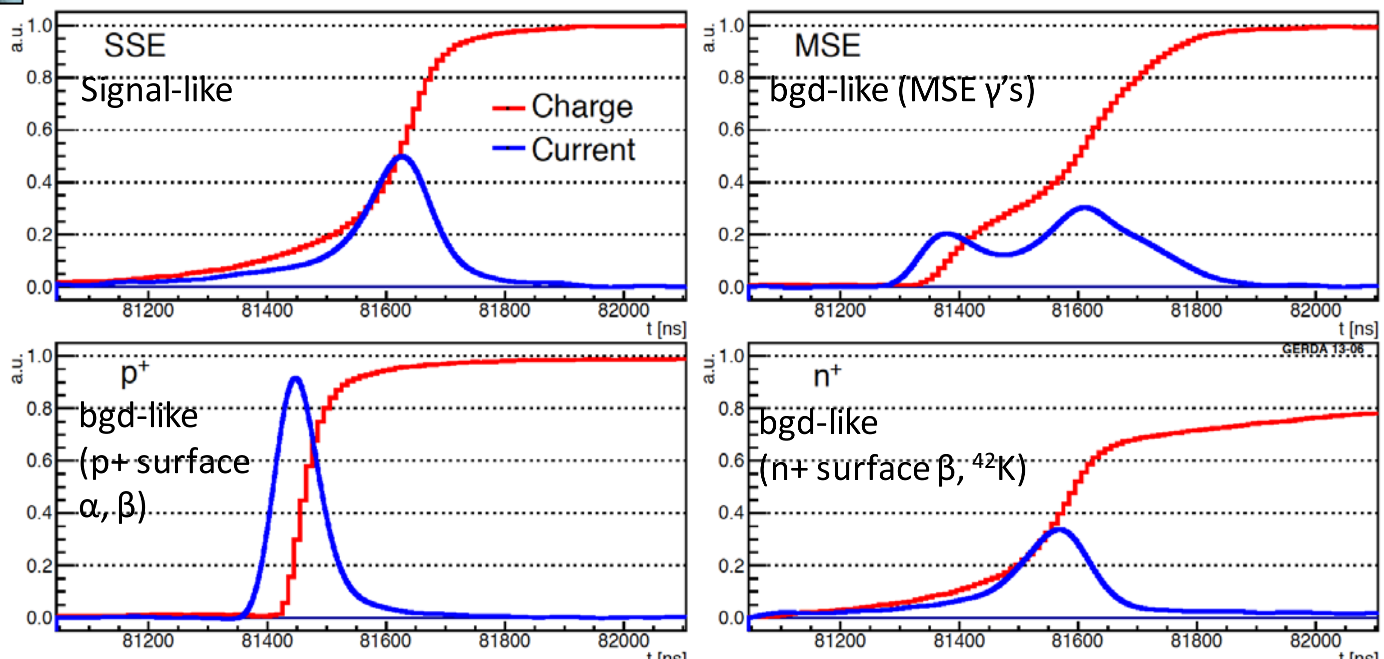
# Pulse shape discrimination: BEGe

EPJC 73 (2013) 2583






PSD discrimination parameter: **A/E**
(simple and robust)



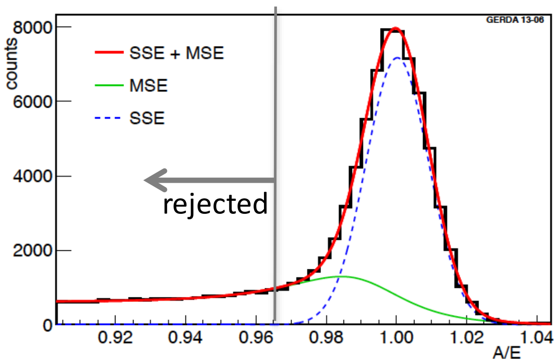

E

A

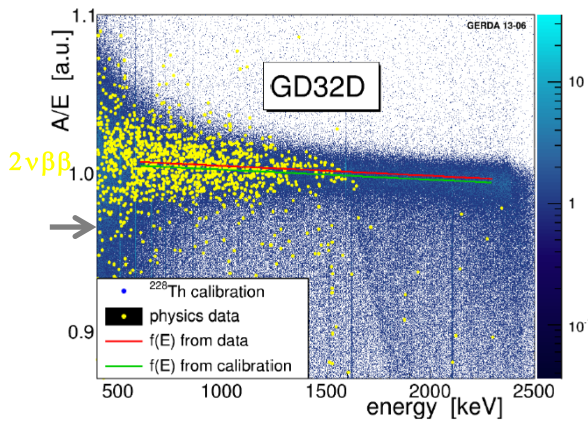
# Pulse shape discrimination: BEGe

EPJC 73 (2013) 2583

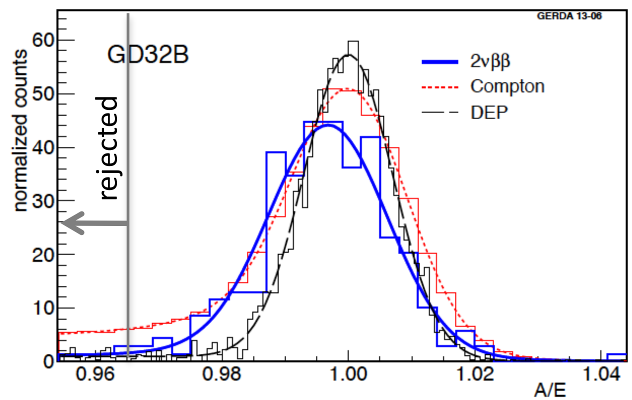
A/E of Compton continuum from calibration



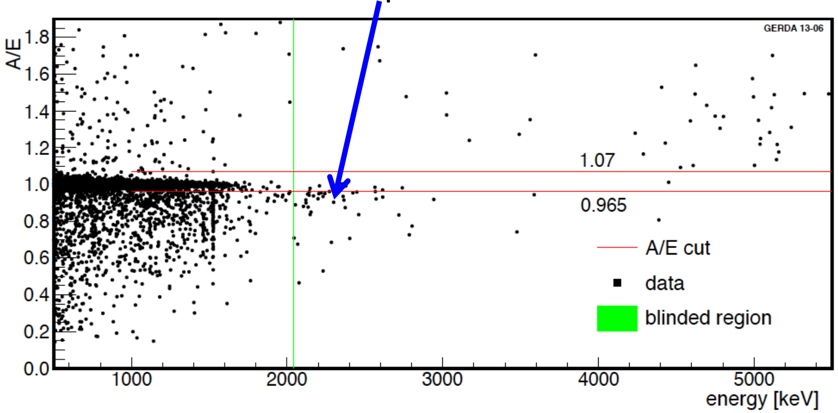

Energy dependence of A/E



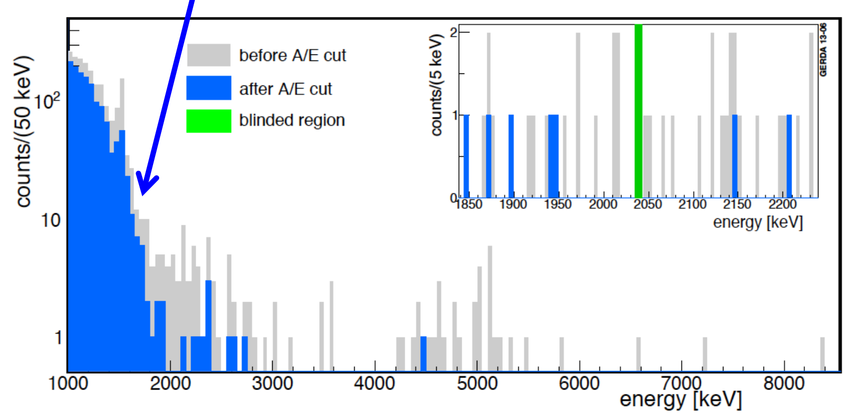

A/E for 2νββ, Compton (1-1.4 MeV), DEP (1592 keV)




$^{42}$K-β n+ surface dominated




2νββ acceptance: 0.91±0.05



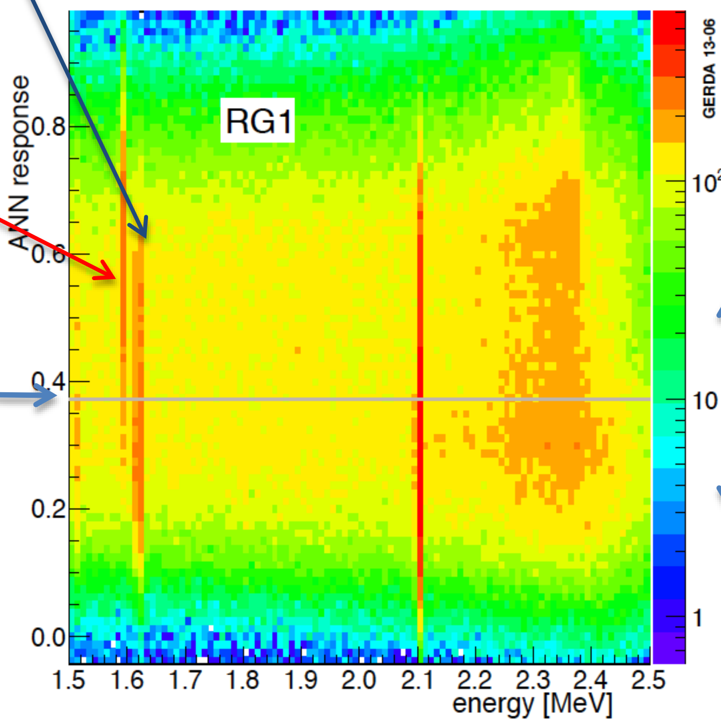

**Rejects > 80% of bkg-like events & 0νββ acceptance: 92±2 %**

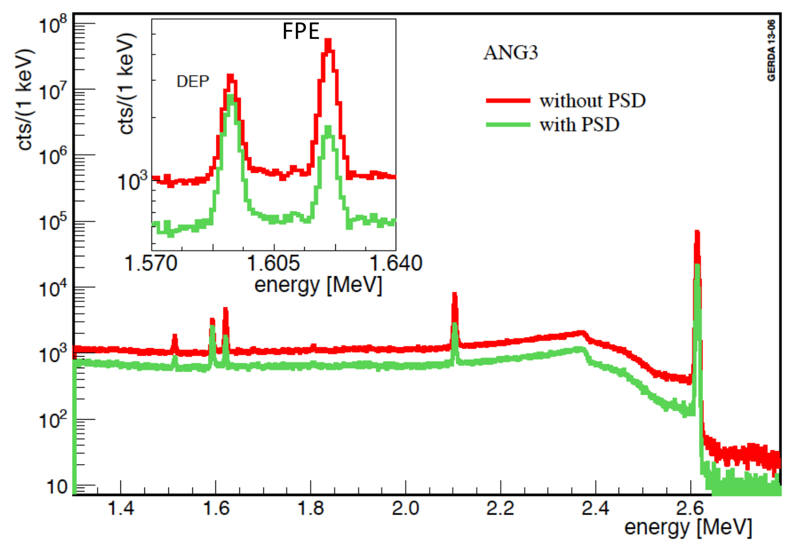
# Pulse Shape Discrimination: Coaxial

**3 independent PSD methods:**

- **likelihood classification** **(for cross-checking)**
- **PSD selection based on pulse asymmetry** **(for cross-checking)**
- **Artificial Neural Network analysis (ANN):** SSE library: training with signal-like $^{208}$Tl DEP ev
  MSE library: training with background-like $^{212}$Bi FEP (1621 keV)

Cut adjusted for each detector to 90% DEP survival

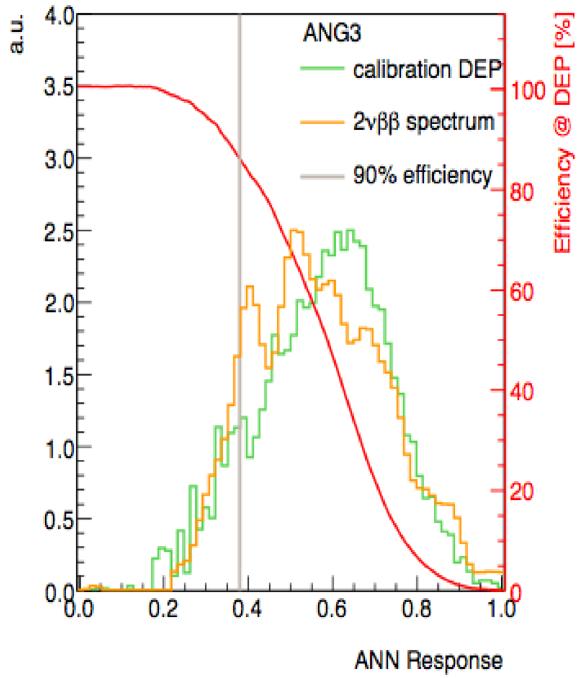


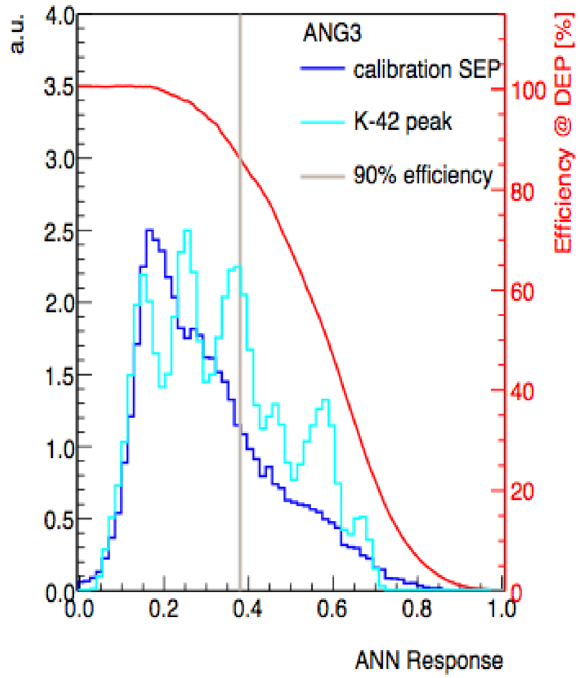



# Neural Network Training with Calibration Data: Coax

EPJC 73 (2013) 2583

- DEP events in the interval $1592\,\mathrm{keV} \pm 1FWHM$ serve as proxy for SSE
- Full energy line of $^{212}Bi$ in the equivalent interval around $1620\,\mathrm{keV}$ are dominantly MSE, taken as background events




**select ANN cut position @ DEP survival = 90%**

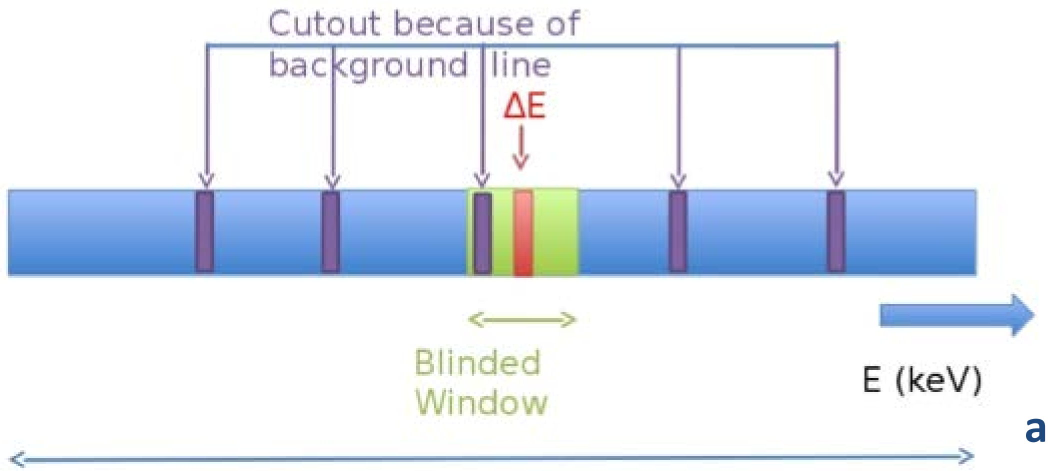
cross checks: 2νββ eff. = 85±5 %, Compton edge eff. = 85-94%,

$^{56}$Co DEP (1576 keV) eff. = 83%-95%

$^{56}$Co DEP (2231 keV) eff. = 83%-93%

- **ANN rejects 45% of background events**
- **0νββ efficiency = 90% +5%/-9%**

# The blinding procedure




$\Delta E = Q_{\beta\beta} \pm 20$ keV

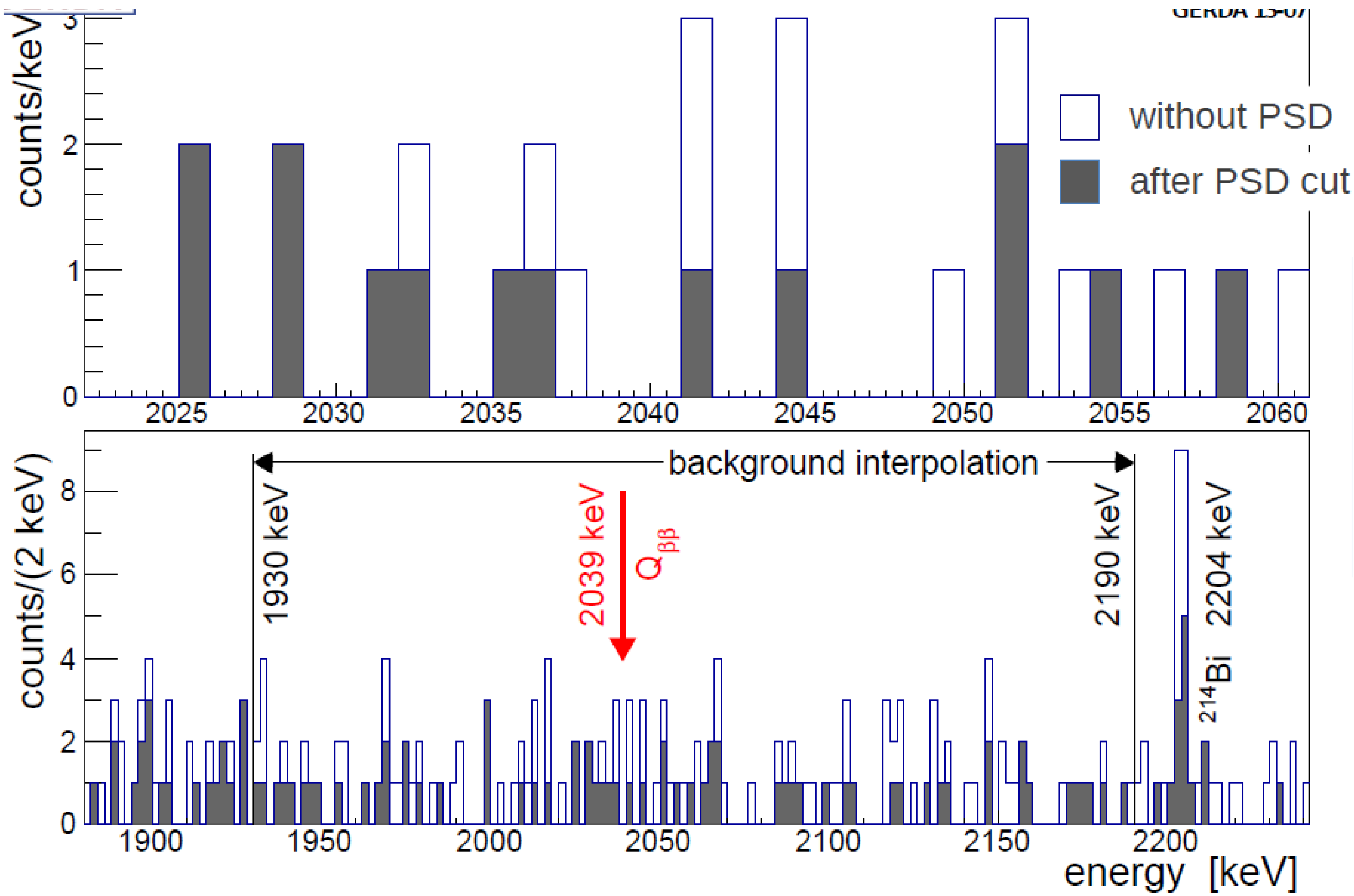
**Energy & pulse of events into [2019-2059] keV automatically removed from data flow**

**Data processing details fixed before unblinding:**
- **quality cuts**
- **pulse shape discrimination parameters**
- **analysis method → three data sets**

**golden = 17.9 kg*yr**
**silver = 1.3 kg*yr**
**BEGe = 2.4 kg*yr**

**Unblinding in June 2013**

# Unblinding: full data set
# (21.6 kg yr & 7 event in blinded window & 3 event survive PSD cut)




**No peak in spectrum at $Q_{\beta\beta}$ +/- 5 keV, event count consistent with bkg**
**⇒ GERDA sets a limit**

# List of events in blinded window $Q_{\beta\beta}$ +/- 5 keV

Table 1: List of all events within $Q_{\beta\beta} \pm 5$ keV

| data set | detector | energy [keV] | date | PSD passed | ANN | A/E | Cut Threshold |
|---|---|---|---|---|---|---|---|
| *golden* | ANG 5 | 2041.8 | 18-Nov-2011 22:52 | no | 0.344 | | 0.366 |
| *silver* | ANG 5 | 2036.9 | 23-Jun-2012 23:02 | yes | 0.518 | | 0.366 |
| *golden* | RG 2 | 2041.3 | 16-Dec-2012 00:09 | yes | 0.682 | | 0.364 |
| *BEGe* | GD32B | 2036.6 | 28-Dec-2012 09:50 | no | | 0.750 | 0.965÷1.070 |
| *golden* | RG 1 | 2035.5 | 29-Jan-2013 03:35 | yes | 0.713 | | 0.372 |
| *golden* | ANG 3 | 2037.4 | 02-Mar-2013 08:08 | no | 0.205 | | 0.345 |
| *golden* | RG 1 | 2041.7 | 27-Apr-2013 22:21 | no | 0.369 | | 0.372 |

**7 events before PSD compare with 5,1 +/- 0,5 expected bkg counts**

**No peak in spectrum at $Q_{\beta\beta}$ +/- 5 keV**

- **Coax.: 6 events**
  **3 of them classified as SSE by ANN**
  **5 of them classified as SSE by at least one other PSD**
- **BEG: 1 event which is rejected by the A/E cut**

**⇒ GERDA sets a limit**

- **No events remain within $Q_{\beta\beta}$ +/- $\sigma_E$ after PSD**

# Parameters of three data sets and counts in blinded window

| data set | $\mathcal{E}$[kg·yr] | $\langle\epsilon\rangle$ | bkg (in 230 keV) | BI †) | cts |
|---|---|---|---|---|---|
| without PSD | | | | | |
| *golden* | 17.9 | $0.688 \pm 0.031$ | 76 | $18 \pm 2$ | 5 |
| *silver* | 1.3 | $0.688 \pm 0.031$ | 19 | $63^{+16}_{-14}$ | 1 |
| *BEGe* | 2.4 | $0.720 \pm 0.018$ | 23 | $42^{+10}_{-8}$ | 1 |
| with PSD | | | | | |
| *golden* | 17.9 | $0.619^{+0.044}_{-0.070}$ | 45 | $11 \pm 2$ | 2 |
| *silver* | 1.3 | $0.619^{+0.044}_{-0.070}$ | 9 | $30^{+11}_{-9}$ | 1 |
| *BEGe* | 2.4 | $0.663 \pm 0.022$ | 3 | $5^{+4}_{-3}$ | 0 |

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

Counts in blinded window (BW)

| Total counts in BW | Expected (bgd only) | Observed |
|---|---|---|
| without PSD | 5.1 | 7 |
| with PSD | 2.5 | 3 |

# From counts to half-life

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

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

$N_A$: Avogadro number

E: exposure

ε: exposure averaged efficiency

$m_{enr}$: molar mass of enriched Ge

$N^{0\nu}$: signal counts / limit

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

$f_{76}$: enrichment fraction

$f_{av}$: fraction of active detector volume

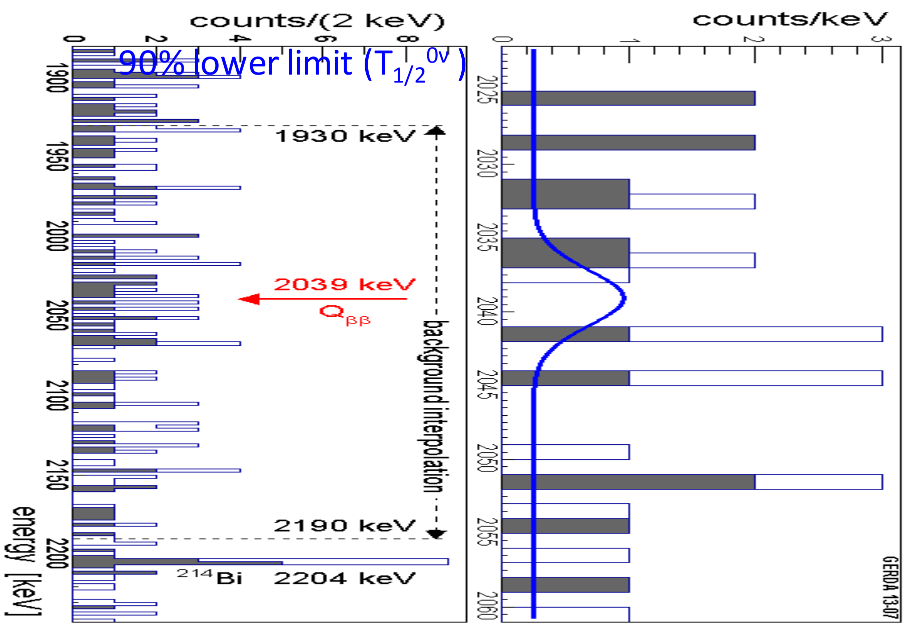
$\varepsilon_{fep}$: full energy peak efficiency for 0νββ

$\varepsilon_{psd}$: signal acceptance

| | $\langle f_{76} \rangle$ | $\langle f_{av} \rangle$ | $\langle \varepsilon_{fep} \rangle$ | $\langle \varepsilon_{psd} \rangle$ | $\langle \varepsilon \rangle$ |
|---|---|---|---|---|---|
| **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 |

# Frequentist and Bayesian limits & sensitivities

*Phys. Rev. Lett. 111 (2013) 122503*




## Frequentist:

- **Profile Likelihood fit** to four parameters:
  3 x bkg level & $1/T^{0\nu}$
  Fix gaussian μ = (2039,06+/-0,2) keV
  σ=(2,0+/-0,1)/(1,4+/-0,1) keV for Coax/BEGe
- Systematic uncertainties on f, ε, μ, σ: MC sampling & averaging
- Best fit: **$N^{0\nu}$=0**
- **No excess** of signal counts above the background
- 90% C.L. lower limit: $T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}$ yr
- Limit on half-life corresponds to $N^{0\nu}$ < 3.5 cts
- MC median sensitivity (90% CL): >2.4×$10^{25}$ yr

## Bayesian:

- Flat prior probability distribution
- Posterior distribution for $T_{1/2}^{0\nu}$ in [0; $10^{-24}$] $yr^{-1}$
- Best fit: **$N^{0\nu}$=0**
- 90% credibility interval: $T^{0\nu}_{1/2} > 1.9 \cdot 10^{25}$ yr
- Median sensitivity: (90% C.I.): > 2.0×$10^{25}$ yr

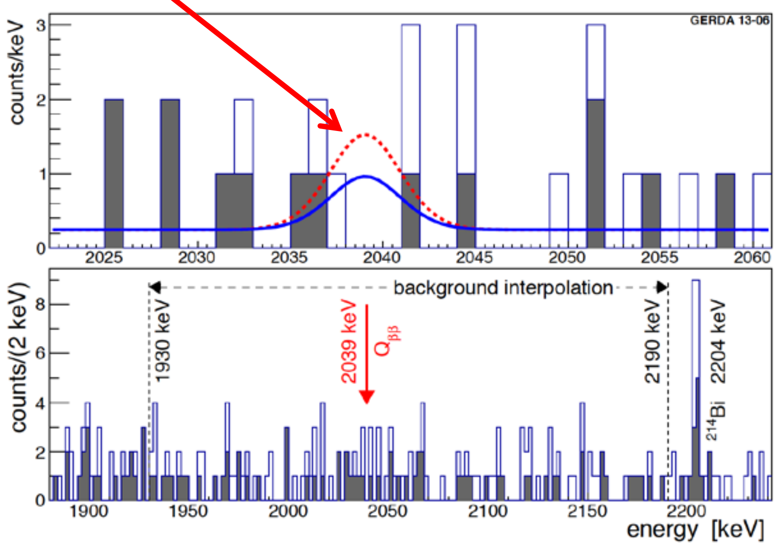
Systematics:

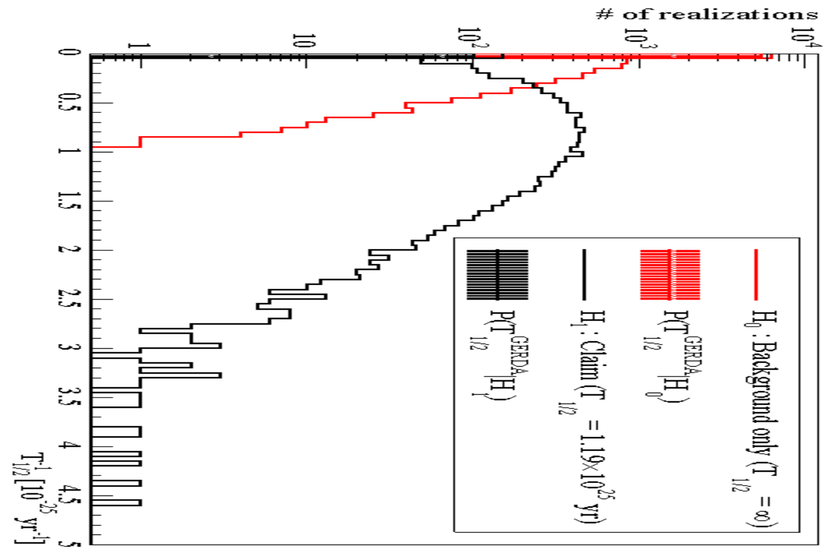
| Parameter | Det./Set | Value | Uncertainty |
|---|---|---|---|
| <ε> w/o PSD | Coax | 0.688 | 0.031 |
| | BEGe | 0.720 | 0.018 |
| Energy res. | Golden | 4.83 keV | 0.19 keV |
| | Silver | 4.63 keV | 0.14 keV |
| | BEGe | 3.24 keV | 0.14 keV |
| Energy scale (keV) | | N.A. | 0.2 keV |
| $\varepsilon_{PSD}$ | Coax | 0.90 | 0.10 |
| | BEGe | 0.92 | 0.02 |

# Comparison with Phys. Lett. B 586 198 (2004) claim

Expectation for claimed $T_{1/2}^{0\nu} = 1.19 \times 10^{25}$ yr (Phys. Lett. B 586 198 (2004)):

5.9±1.4 signal over 2.0±0.3 bgd in ±2σ energy window to be compared with 3 cts (0 in ±1σ)




**H1**: claimed signal: 5.9±1.4

**H0**: background only

**Bayes factor**: P(H1)/P(H0 )=0. 024

**p-value** from profile likelihood

P(N=0 = 0|H1 ) = 0. 01 (0.006 if 1/T unconstrained)

➔Claim refuted with high probability

# Summary

- **GERDA Phase I design goals reached:**
  - Background index after PSD: 0.01 cts / (keV kg yr)
  - Exposure 21.6 kg yr

- **Observe 3 events in $Q_{\beta\beta}$ =** $\pm$ 5 keV with expected bkg of 2.5$\pm$0.3
  $\Rightarrow$ no signal

- **No 0νββ-signal observed at $Q_{\beta\beta}$ = 2039 keV; best fit: $N^{0\nu}$=0**
  - Background-only hypothesis $H_0$ strongly favored
  - KK claim strongly disfavored (independent of NME and of physical mechanism generating 0ν2β)

- **Profile likelihood fit to PSD Spectrum:** $T_{1/2}^{0\nu} > 2.1\times10^{25}$ yr (90% C.L.)

**Limit on half-life:**

GERDA+IGEX+HdM: $T_{1/2}^{0\nu} > 3.0\times10^{25}$ yr (90% C.L.) ($\langle m_{ee}\rangle < 0.2\text{-}0.4$ eV)

- **The claimed signal (without PSD) is ruled out by GERDA at 99% without any model dependence**

# GERDA phase II: goal

**sensitivity $T^{0\nu}$(Ge-76) ~ 1.4 ·$10^{26}$ yr at 100 kg·yr**

► **reduce BI by another order of magnitude to 0.001**

more BEGe detectors with better PSD (& resolution)
instrumentation of LAr to veto specific backgrounds
less & cleaner material in detector holders, cables, ..

► **get exposure of ~100 kg·yr within 3 years**

double detector mass (15 kg coaxial + 20 kg BEGe)

**Thank you !**

감사합니다!

**Back up slides**

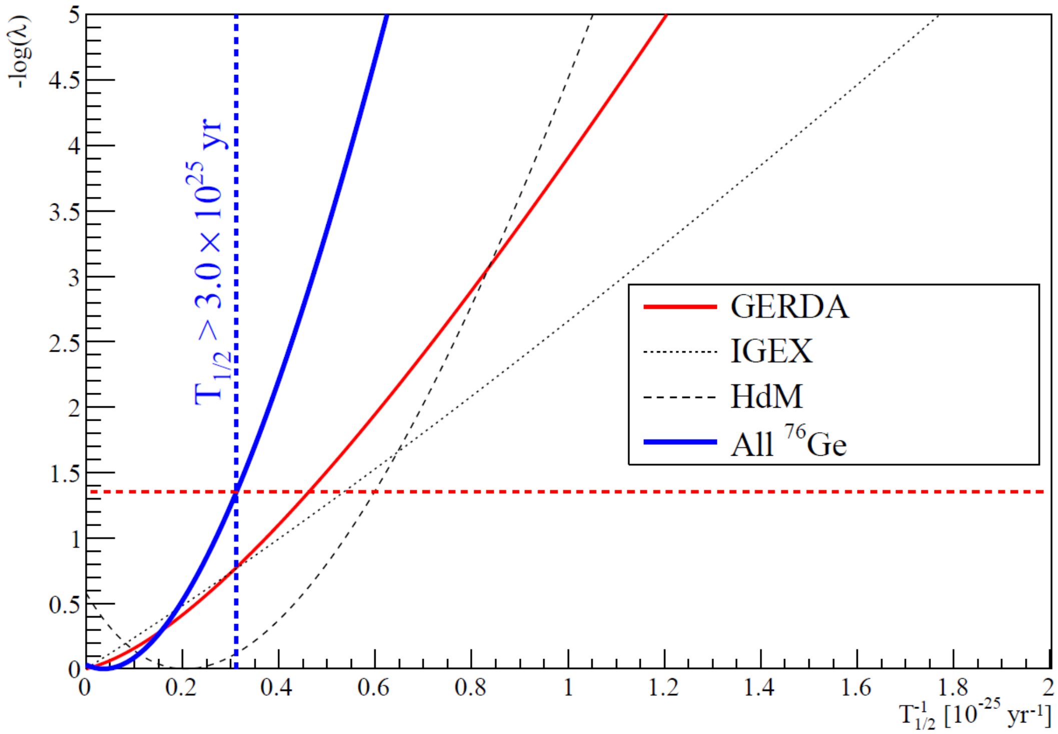
## Summary of the results

- Best fit gives 0 counts both for PL and BA: no excess is visible.
- 2004 KK claim predicted $5.9 \pm 1.4$ signal events over $2.0 \pm 0.3$ bkg events in $Q_{\beta\beta} \pm 2\sigma$.
- 3 events are observed in $Q_{\beta\beta} \pm 2\sigma$, 0 in $Q_{\beta\beta} \pm \sigma$.
- Claim refuted with high probability.

## Combination with other experiments

- Combining with HdM 2001 and IGEX 2002:
  $T^{0\nu}_{1/2} > 3 \cdot 10^{25}$ yr (90%) C.L. (same with Bayesian approach).
- Limit on effective Majorana neutrino mass:
  $m_{ee} < 0.2 - 0.4$ eV

# Combined analysis with HdM and IGEX experiments




HdM: Eur. Phys. J. A 12, 147 (2001)
IGEX: Phys. Rev. D 65, 092007 (2002),
Phys. Rev. D 70 078302 (2004)

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

Identical limits with
Frequentists & Bayesian analysis

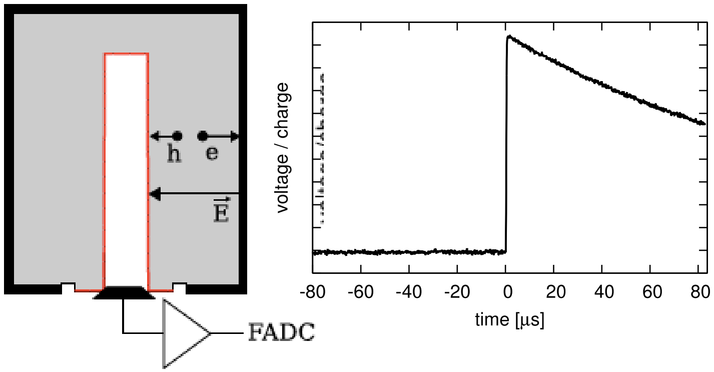
Bayes Factor: P(H1)/P(H0 )=2×$10^{-4}$ strongly disfavors claim

Comparison is independent of NME and of physical mechanism which generates 0νββ

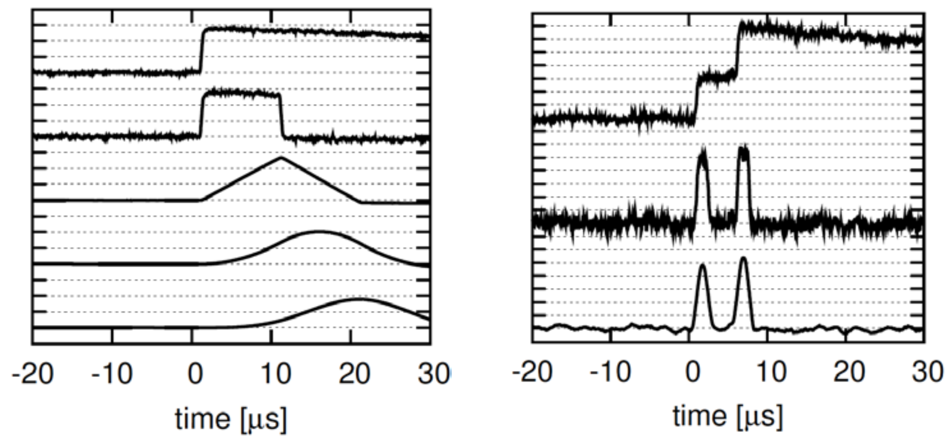
# Data processing and selection

Eur. Phys. J. C (2013) 73:2330
arXiv:1212.4067

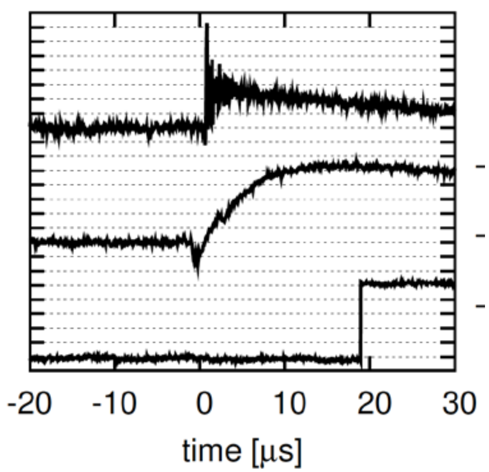
Read-out and signal structure




Digital signal processing to extract amplitude, rise time, etc.

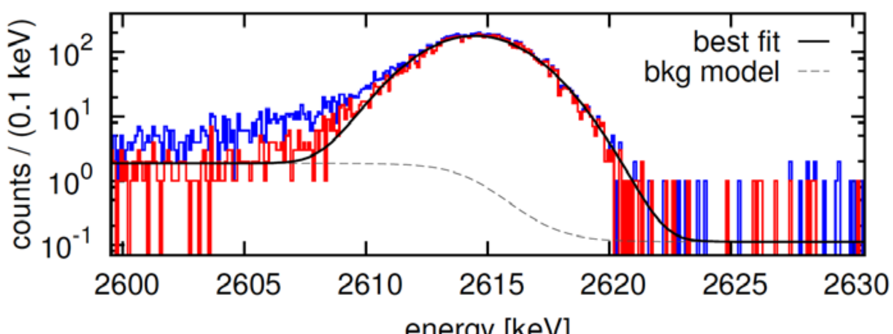



Data selection and quality monitoring




Examples of non-physical events

Calibration of energy scale ($^{228}$Th)



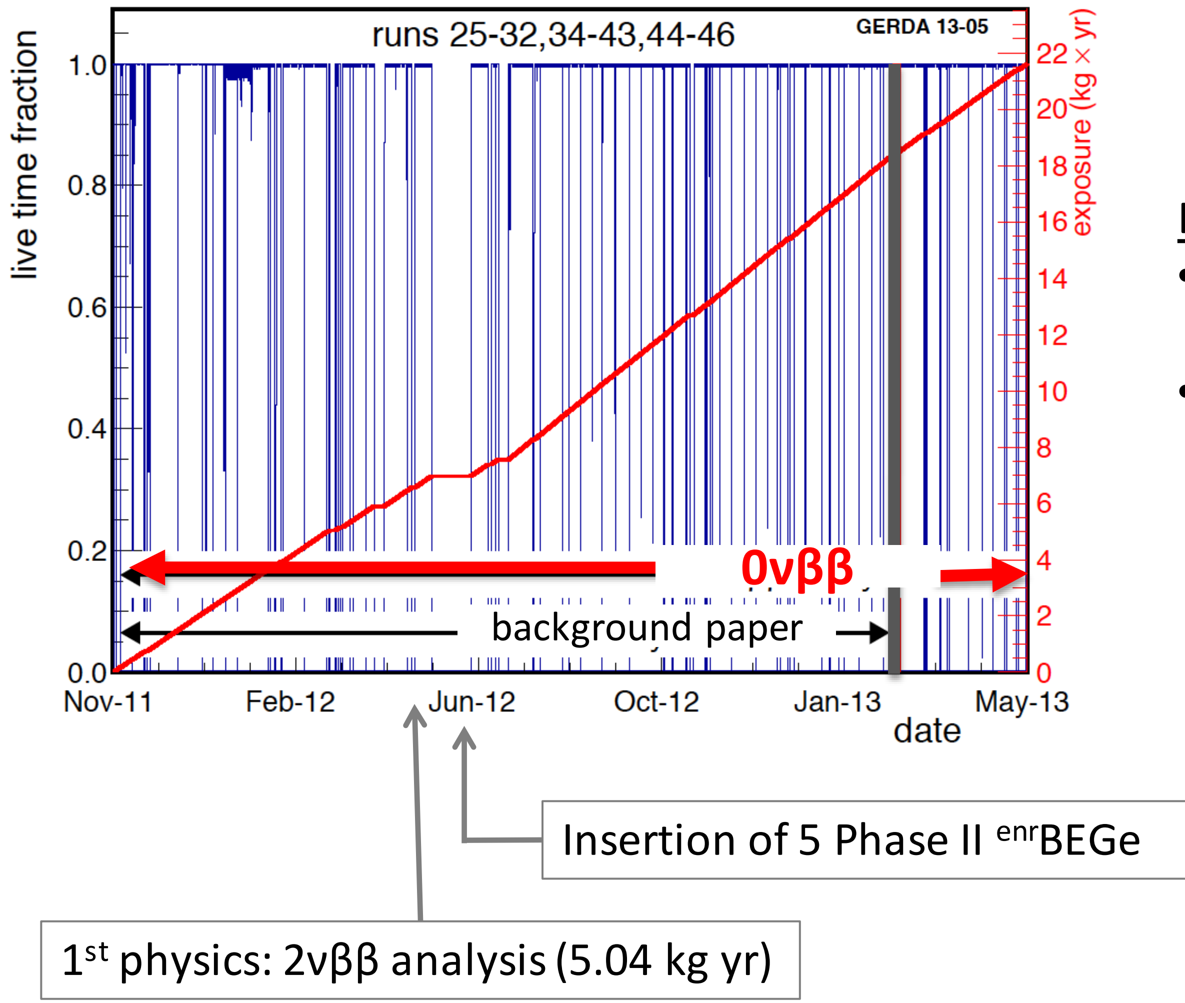

- Data processing frame work 'Gelatio'
- 2nd independent data processing software for cross check

# Data taking

Eur. Phys. J. C (2013) 73:2330
arXiv:1212.4067

Total exposure for 0νββ analysis: 21.6 kg yr

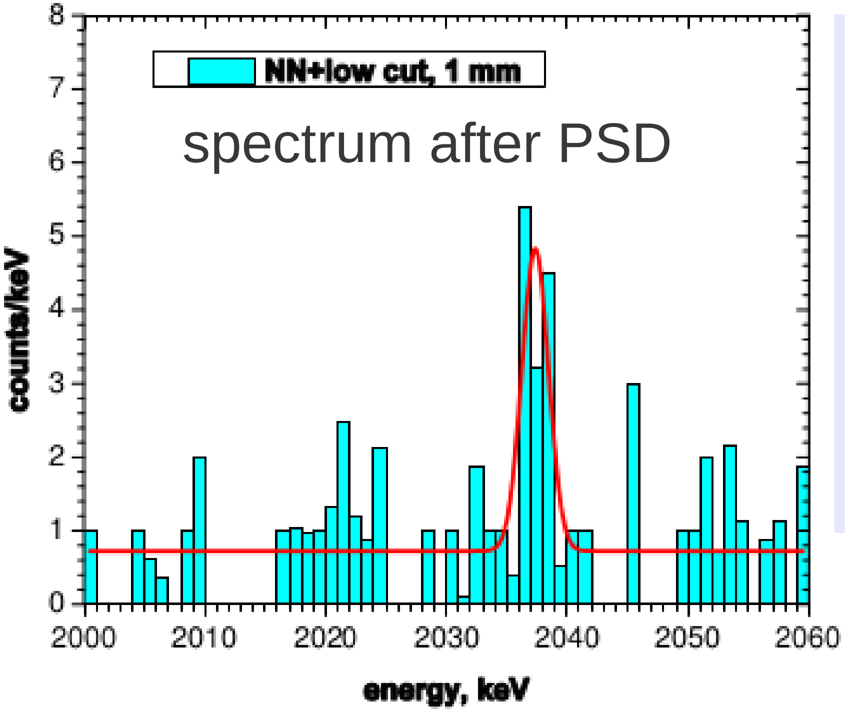
(bi-)weekly calibration runs ('spikes')




Data blinding:

- All events in $Q_{\beta\beta}$±20 keV removed in Tier 1
- 2 copies of raw data kept for processing after unblinding

# 2006 publication: Mod.Phys. Lett. A21 p. 1547-1566




fit gives 11.32±1.75 signal events

→

error on signal count not correct
since smaller than Poisson error

PSD based on 3 different neural networks & library of SSE pulses

event accepted IF pulse in library OR found by neural network of Ref. 16 but not by the other two neural networks

NO event overlap between the 2 sets!?

statement of publication:

- "multi site events are suppressed by 100%",
- $0\nu\beta\beta$ efficiency = 1 used for $0\nu$

efficiency factor not considered
→ calculation of $T^{0\nu}_{1/2}$ not correct
→ GERDA does not use this result