Search of Neutrinoless Double Beta Decay with the GERDA Experiment

Joint OEPG and SPS Meeting 2013

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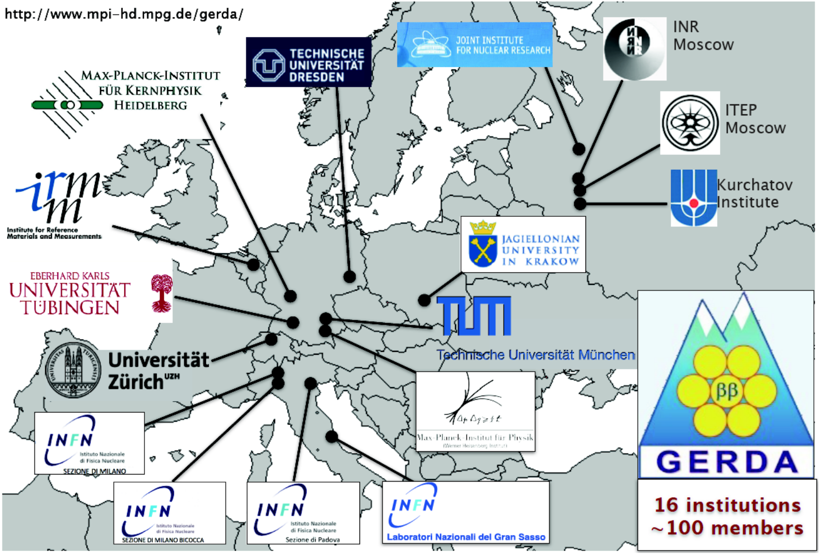
Linz 04.09.13

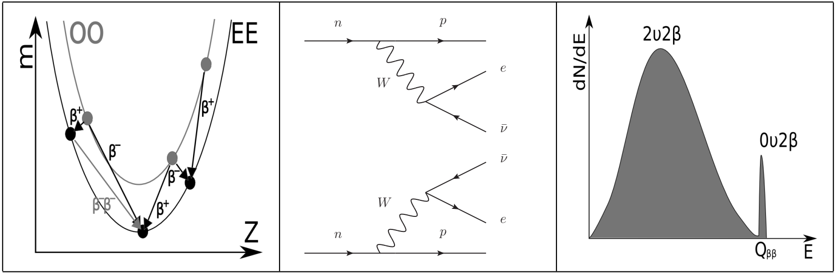
The GERDA Collaboration

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



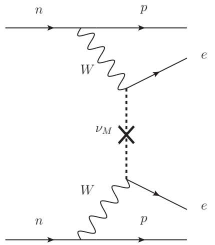
16 institutions
~100 members

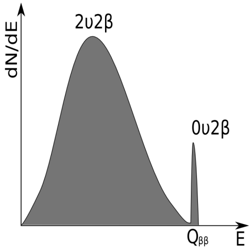
The Double Beta Decay



- If β-decay energetically forbidden $\rightarrow$ $2\nu2\beta$ decay might be possible.
- $2\nu2\beta$ spectrum is a continuum ending at the Q-value.
- $\mathrm{T}^{2\nu}_{1/2} \sim 10^{19-21}$ years.
- For ^{76}Ge: $\mathrm{T}^{2\nu}_{1/2} = (1.84^{+0.14}_{-0.10}) \cdot 10^{21}$ yr*

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





Theoretical aspects of $0\nu2\beta$ decay

- Expected decay rate:
  $$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}(Q,Z)\left|M^{0\nu}\right|^2\langle m_{ee}\rangle^2$$
  $G^{0\nu}(Q,Z) =$ Phase Space integral
  $\left|M^{0\nu}\right|^2 =$ nuclear matrix element
  $\langle m_{ee}\rangle^2 = \sum_i U^2_{ei} m_i =$ effective ν mass
- Signature: expected peak at
  $Q_{\beta\beta} = m(A,Z) - m(A,Z-2) - 2m_e$

If $0\nu2\beta$ decay is discovered:

- Lepton number is violated
- ν's are Majorana particles
- Physics beyond the Standard Model

Experimental requirements

Maximum measurable $0\nu 2\beta$ halflife:

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

a = enrichment fraction

ε = efficiency

M = detector mass

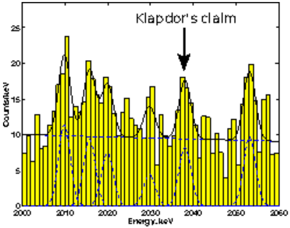
t = exposure

BI = Background Index

ΔE = energy resolution

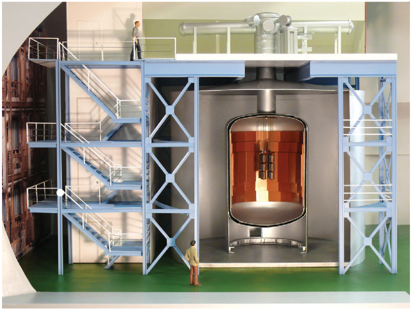
Advantages of Ge
Disadvantages of Ge

State of the art for Ge experiments



- HdM 2001: $T_{1/2}^{0\nu} > 1.9 \cdot 10^{25}$ y (90%CL)
  Eur. Phys. J. A12 (2001) 147-154
- KK (HdM) 2004: $T_{1/2}^{0\nu} = 1.19 \cdot 10^{25}$ y
  NIM A 522 (2004), PLB 586 (2004)
- IGEX: $T_{1/2}^{0\nu} > 1.6 \cdot 10^{25}$ y (90%CL)
  Phys. Rev. D 65 (2002) 092007

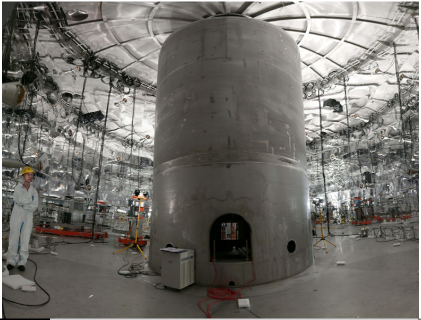
The GERDA Experiment



- Located in Hall A at LNGS
- 3800 mwe overburden
- Phase I: 18 kg of enriched detectors (HdM and IGEX), BI $= 10^{-2}$counts/(keV·kg·yr)
- Phase II: + 20 kg of enr Ge, BI $= 10^{-3}$counts/(keV·kg·yr)

Experiment structure

- 590 m^3 Water Tank to adsorb neutrons and veto μ's
- 64 m^3 Liquid Argon (LAr) for cooling and shielding
- Minimal amount of material close to the diodes



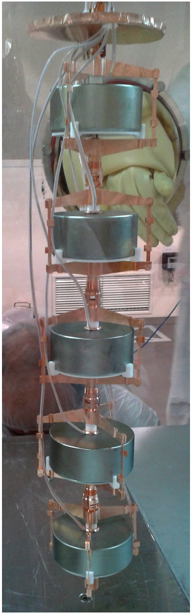
The GERDA Detectors

Coaxial detectors

- 86% isotopically enriched in ^{76}Ge
- 5 enr detectors from HdM, 3 enr from IGEX, 1 natural from GTF
- Total mass: 17.7 kg
- Two detectors turned off because of high leakage current → total mass 14.6 kg

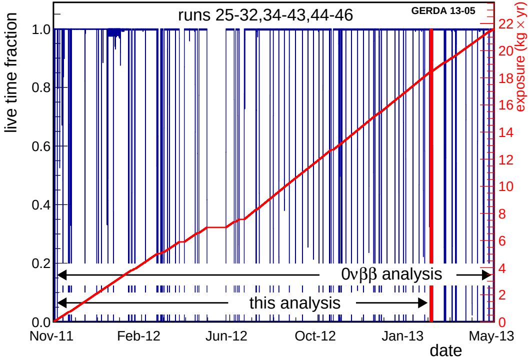
BEGe detectors

- BEGe = Broad Energy Germanium
- 1‰ FWHM at 2.6 MeV
- Enhanced Pulse Shape Discrimination (PSD)
- ∼ 20 kg of BEGe's produced and tested
- 5 BEGe's inserted in GERDA in Juli 2012



GERDA Phase I Data Taking

- Total exposure: 21.6 kg·yr
- Spikes: (Bi)-weekly calibration runs
- Flat parts: BEGe's insertion (June 2012), maintainance operations

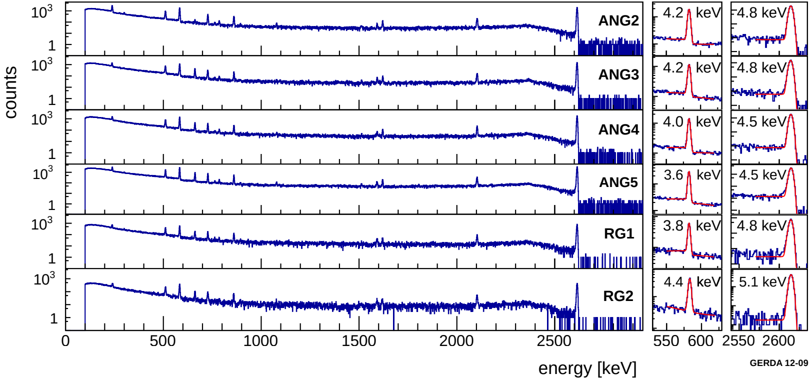


Blinding

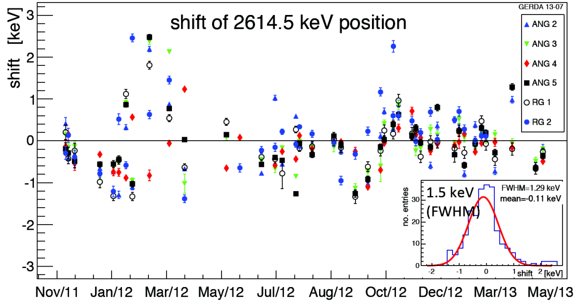
- All events in $Q_{\beta\beta} \pm 20$ keV automatically removed
- Unblinding only after analysis procedure and background model were defined and freezed.

Calibration of the GERDA Data

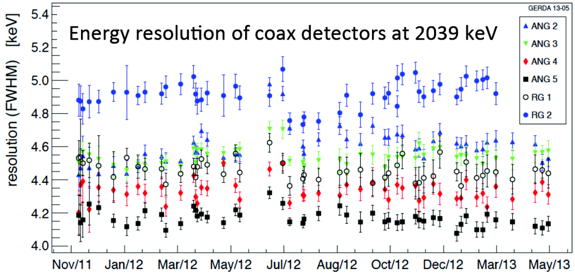
- Spectra calibrated (bi)-weekly with ^{228}Th sources
- Data useful also for monitoring the resolution and gain stability over time
- FWHM at $Q_{\beta\beta}$: 4.8 keV for the coaxial detectors, 3.2 keV for the BEGe's (space for improvement with better filtering).

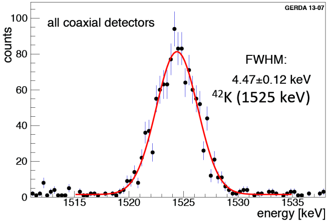


Time Stability

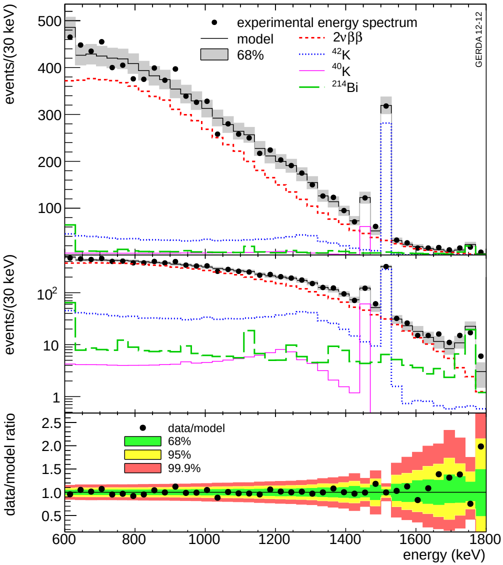


detector	FWHM [keV]
SUM-coax	
ANG2	5.8 (3)
ANG3	4.5 (1)
ANG4	4.9 (3)
ANG5	4.2 (1)
RG1	4.5 (3)
RG2	4.9 (3)
mean coax	4.8 (2)
SUM-BEGe	
GD32B	2.6 (1)
GD32C	2.6 (1)
GD32D	3.7 (5)
GD35B	4.0 (1)
mean BEGe	3.2(2)

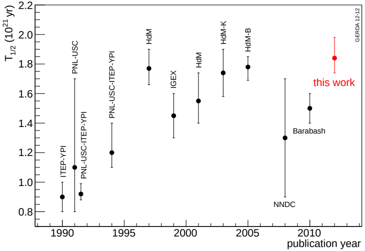




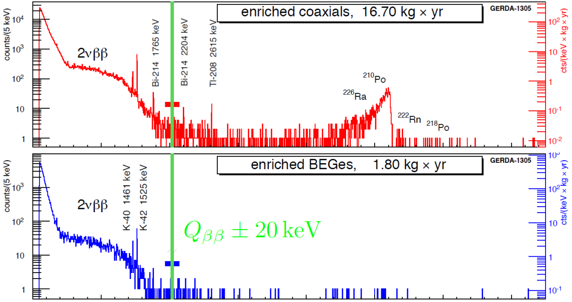
$2\nu2\beta$ Measurement

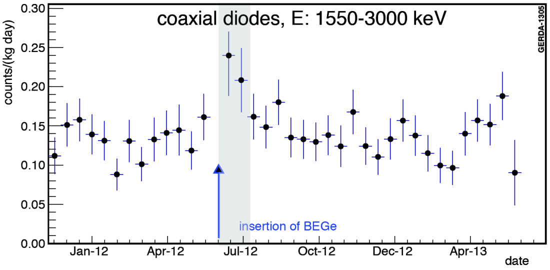


- Measured by GERDA with 5.04 kg·yr exposure
- $T^{2\nu}_{1/2} = (1.84^{+0.14}_{-0.10}) \cdot 10^{21}$ yr
- J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110



The Background of GERDA Phase I



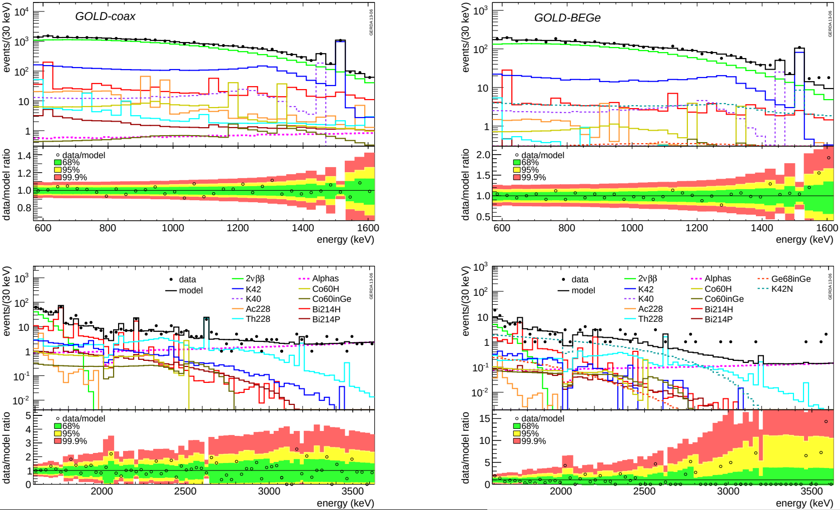


- Split coaxial data in two sets, according to the BI
- Golden: all the coax data, but Juli 2012
- Silver: coax data taken in Juli 2012 (after BEGe insertion)

dataset	exposure [kg·yr]
Golden	17.90
Silver	1.30
BEGe	2.40

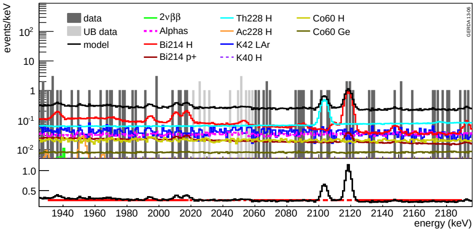
The Background of GERDA Phase I

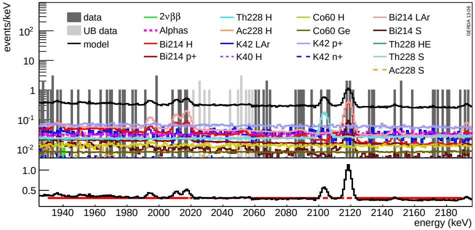
- Background Model published: arXiv:1306.5084v1
- Minimal model: only visible contributions considered
- Maximal model: all possible contributions included



Background prediction at $Q_{\beta\beta}$

- Both minimal and maximal model predict a flat bkg at $Q_{\beta\beta}$





BI before PSD interpolated in the Region of Interest:

Golden Coaxial:
$1.75^{+0.26}_{-0.24} \cdot 10^{-2}$ counts/(keV·kg·yr)

BEGe's:
$3.6^{+1.3}_{-1.0} \cdot 10^{-2}$ counts/(keV·kg·yr)

Gaussian fit with flat background in the 1930-2190 keV region, excluding known gamma peaks at 2104 and 2119 keV.

Pulse Shape Discrimination (arXiv:1307.2610)

What to discriminate?

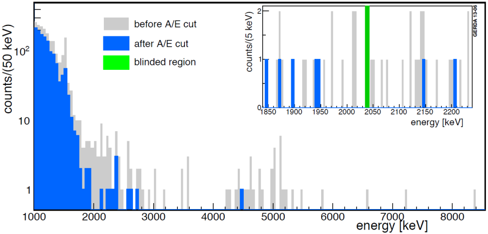
- $0\nu2\beta$ signals are contained in a small region of the Ge detector $\rightarrow$ single-site
- Gamma events can do multiple scattering $\rightarrow$ multi-site

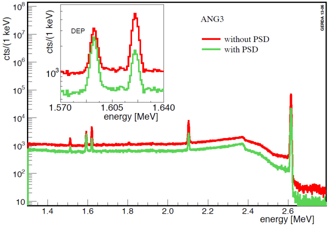
BEGe's: A/E cut

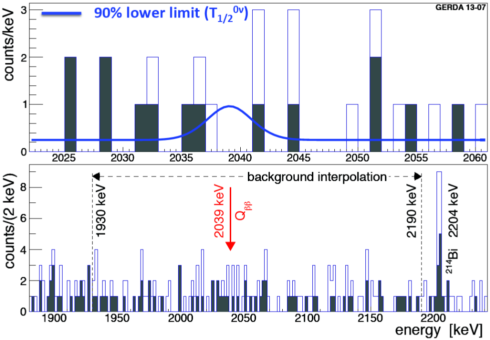
- A = amplitude of current pulse, E = energy
- Rejects 80% of background-like events
- Accept 90% of signal-like events

Coaxial: Artificial Neural Network (+ 2 crosscheck methods)

- Rejects 45% of background-like events
- Accept 90% of signal-like events







data set	detector	energy [keV]	date	PSD passed
golden	ANG5	2041.8	18-Nov-2011 22:52	no
silver	ANG5	2036.9	23-Jun-2012 23:02	yes
golden	RG2	2041.3	16-Dec-2012 00:09	yes
BEGe	GD32B	2036.6	28-Dec-2012 09:50	no
golden	RG1	2035.5	29-Jan-2013 03:35	yes
golden	ANG3	2037.4	02-Mar-2013 08:08	no
golden	RG1	2041.7	27-Apr-2013 22:21	no

Observed and predicted events at $Q_{\beta\beta} \pm 5$ keV:

	Observed	Predicted Bkg
No PSD	7	5.1
PSD	3	2.5

GERDA result on $0\nu2\beta$

- Profile Likelihood (PL):

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

- Bayesian Analysis (BA) (flat prior for $T^{0\nu}_{1/2}$):

  $T^{0\nu}_{1/2} > 1.9 \cdot 10^{25}$ yr (90%) C.I.

- arXiv:1307.4720

GERDA Phase I Results

Summary of the results

- Best fit gives 0 counts both for PL and BA: no excess is visible.
- 2004 KK claim predicted 5.9 ± 1.4 signal events over 2.0 ± 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

Outlook

- Results accepted by PRL for publication!
- Work is ongoing with the preparation of GERDA Phase II...

Backup: Crosscheck: $2\nu2\beta$ decay halflife

Value of $T^{2\nu}_{1/2}$ using the full dataset and the full bkg model:

Model	ε [kg·yr]	$T^{2nu}_{1/2} \cdot 10^{21}$ 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	$1.96^{0.13}_{-0.05}$
J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110	5.04	$1.84^{+0.09}_{-0.08}(fit)^{+0.11}_{-.010}(syst)$

Backup: From counts to halflife

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

$$\epsilon = f_{76} \cdot f_{AV} \cdot \varepsilon_{FEP} \cdot \varepsilon_{PSD}$$

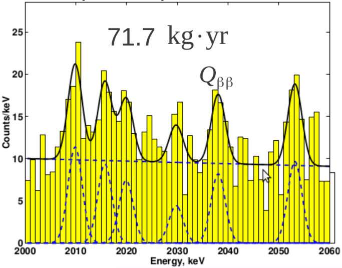
Dataset	Exposure [kg·yr]
Golden-coax	17.9
Silver-coax	1.3
BEGe	2.4

$N_A =$ Avogado Number
$E =$ Exposure
$\varepsilon =$ Exposure averaged efficiency
$m_{enr} =$ Molar mass of enriched Ge
$N^{0\nu} =$ Signal counts /limit

$f_{76} =$ Enrichment fraction
$f_{AV} =$ Active Volume detector fraction
$\varepsilon_{FEP} =$ Full Energy Peak efficiency for $0\nu2\beta$
$\varepsilon_{PSD} =$ Signal acceptance

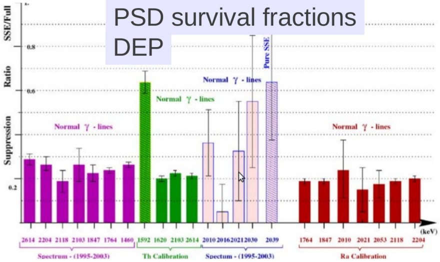
	$\langle f_{76} \rangle$	$\langle f_{AV} \rangle$	$\langle \varepsilon_{FEP} \rangle$	$\langle \varepsilon_{PSD} \rangle$	ε
Coax	0.86	0.87	0.92	$0.90^{+0.05}_{-0.09}$	$0.619^{+0.044}_{-0.070}$
BEGe	0.88	0.92	0.90	0.92 ± 0.02	0.663 ± 0.022

a) 2004 publications: NIM A522 371 & PL B586 198



entire data set: 71.7 kg·yr (active mass)
28.75 ± 6.86 signal events
$T^{0\nu}_{1/2} = \left(1.19^{+0.37}_{-0.23}\right) \cdot 10^{25}$ yr

data for PSD analysis: 51.4 kg·yr
19.58 ± 5.41 signal events
$T^{0\nu}_{1/2} = \left(1.25^{+0.49}_{-0.27}\right) \cdot 10^{25}$ yr



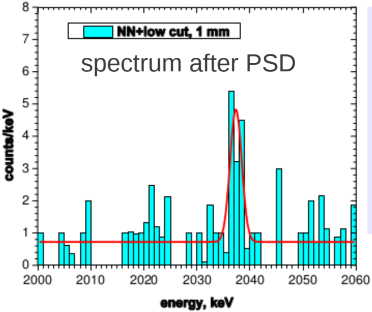
with PSD applied:
12.36 ± 3.72 events
DEP survival fraction ~ 62%
→ $T^{0\nu}_{1/2} = 1.23 \cdot 10^{25}$ yr

Without efficiency correction:
$T^{0\nu}_{1/2} = 1.98 \cdot 10^{25}$ yr

No efficiency correction is applied in any publication!

Backup: Why GERDA does not use KK 2006 result?

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



fit gives 11.32±1.75 signal events

$\rightarrow T_{1/2}^{0\nu} = (2.23^{+0.44}_{-0.31}) \cdot 10^{25}$ yr

error on signal count not correct since smaller than Poisson error

PSD based on 3 previous methods (2 neural networks + pulse boardness) & 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 $T_{1/2}^{0\nu}$

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