Recent results from GERDA

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INFN-LNGS, GERDA Collaboration

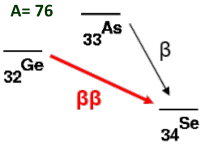
Rencontres de Moriond
La Thuile - March 5th, 2013

OUTLINE:

- GERDA motivations
- GERDA design
- GERDA status

GERDA motivations

The GERmanium Detector Array experiment is an ultra-low background experiment designed to search for ^{76}Ge $0\nu\beta\beta$ decay.



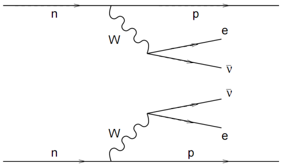
$Q_{\beta\beta} = 2039$ keV

$2\nu\beta\beta$

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

$\Delta L = 0 \Longrightarrow$ Predicted by s.m.

Observed.



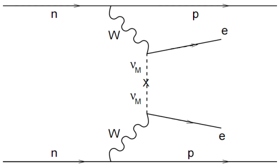
$0\nu\beta\beta$

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

$\Delta L = 2 \Longrightarrow$ Physics beyond s.m.

Observed?

Light Majorana neutrino exchange



$Q = M_i - M_f - 2m_e$

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}|M^{0\nu}|^2 \frac{m^2_{\beta\beta}}{m^2_e}$$

$m_{\beta\beta} \equiv |\sum_{i=1}^{3} U^2_{ei} m_i|$

$\equiv$ effective Majorana mass

information on the absolute mass scale!

Schechter-Valle: $0\nu\beta\beta \Longrightarrow$ Majorana ν

Part of Heidelberg-Moscow Collaboration claimed evidence for $0\nu\beta\beta$ observation of ^{76}Ge

$T^{0\nu}_{1/2} = 1.19(0.69 - 4.18)$ $\times 10^{25}$ yr (3σ range)

Phys. Lett. B 586, 198 (2004)

$T^{0\nu}_{1/2} = 2.23^{+0.44}_{-0.31} \times 10^{25}$ yr

Mod.Phys.Lett.A21:1547-1566,2006)

GERDA first goal:
check the HdM claim

^{76}Ge $0\nu\beta\beta$ experiments

HPGe detectors technology (ionization)

Ge as source and detector
in a low background environment.

^{76}Ge natural abundance: 7%
$\Longrightarrow$ Enrichment $\sim$ 86% ^{76}Ge

Advantages

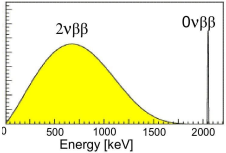
- 4π solid angle coverage
- Industrial techniques and facilities available to enrich the material
- High purity
- Excellent energy resolution

Disadvantages

- Low $Q_{\beta\beta}$ value (lower than ^{208}Tl 2614 keV) $\Longrightarrow$ background
- Enrichment is expensive (but convenient)

Measured quantity for $\beta\beta$ events:
sum of the electrons kinetic energies

$2\nu\beta\beta$: not a constant (a part of the released energy is carried away by neutrinos)
$0\nu\beta\beta$: constant!



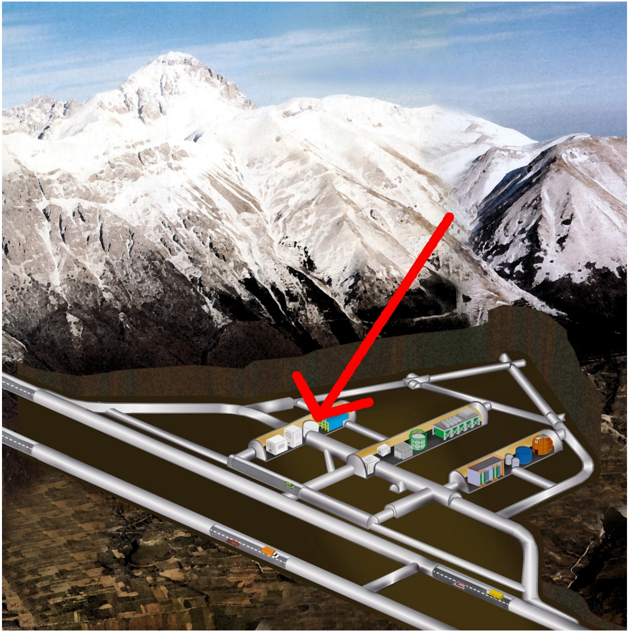
Sensitivity

$$T^{0\nu}_{1/2}(n\sigma\, CL) \sim \frac{\ln 2}{n}\frac{N_A}{A}\alpha\epsilon\sqrt{\frac{M\cdot t}{B\cdot\Delta E}}$$

(α isotopic abundance, ϵ detector efficiency,
M detector mass, ΔE energy resolution,
B background index, t measuring time,
A isotope molar mass)

Low background $\Longrightarrow$ better sensitivity!

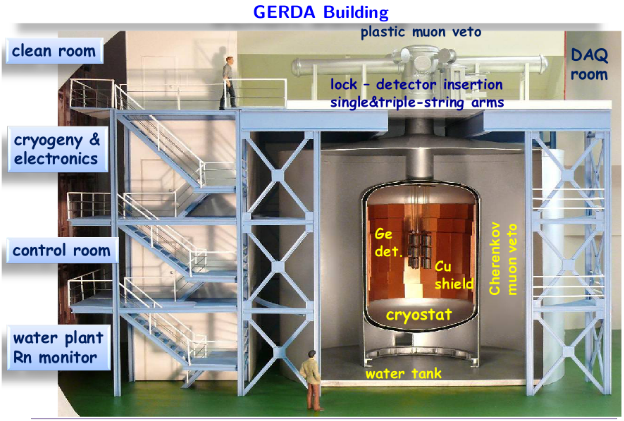
GERDA @ LNGS



The GERDA experiment is hosted in the Hall A of the Gran Sasso Laboratory (INFN)

1400 m of rock
3800 m.w.e.
Suppression of μ-flux$> 10^6$

The GERDA setup



Water tank
$\varnothing = 10$ m
$h = 8.9$ m
$V\ water = 590$ m^3
The water tank acts as an active Cherenkov veto

Cryostat
$\varnothing = 4$ m
H= 5.88 m
Filled by LAr

LAr
Volume $\sim$ 64 m^3
T= 88.8 K

Naked detectors in LAr!
LAr $\rightarrow$ Passive shielding, Cooling, Active veto detecting scintillation light (Phase II)
Detectors are organized in strings - Low mass holders
The current lock system supports 2 arms = 3+1 strings of detectors.

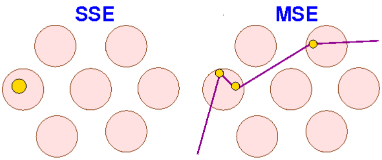
Events identification

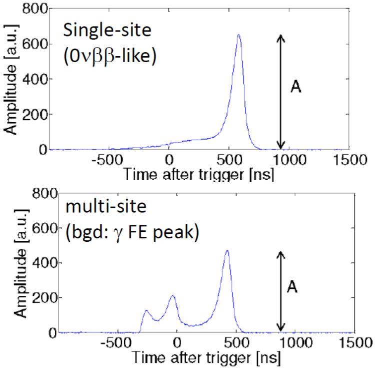
How to understand the nature (signal or background?) of events around $Q_{\beta\beta}$?

- First step: filter events in coincidence with a signal
  - from muon-veto
  - from liquid Argon instrumentation (Phase II)
- Second step: discriminate Single & MultiSite Events

SSE: $\beta\beta$, DEP

MSE: Compton

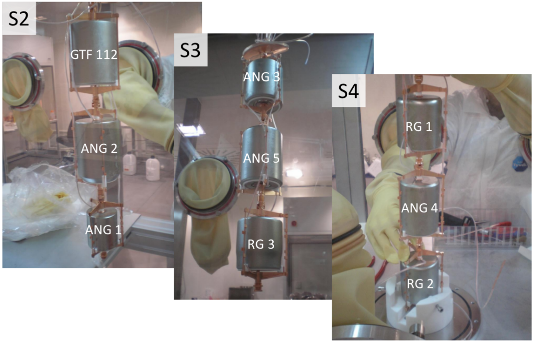




Second step approaches:

- Anti-coincidence of detectors
- Pulse shape analysis

GERDA detectors: coaxials



8 enriched detectors in the 3-string arm.
2 detectors are not working due to high leakage current.
Total mass of working enriched coaxial detectors:
$\sim$ 14.6 kg
Coaxial enriched detectors come from HdM and IGEX experiments!

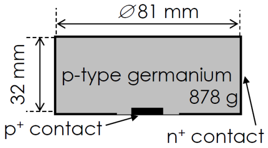
Strings inside mini-shrouds (thin copper shields)

Field-Free environment in the cryostat

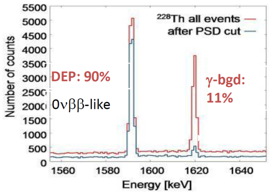
GERDA detectors: BEGes

New enriched detectors have been built.
BEGe detectors from Canberra have been chosen because of good PSD capabilities
JINST 4 P10007

Design for a BEGe string



PSD based on A/E ratio



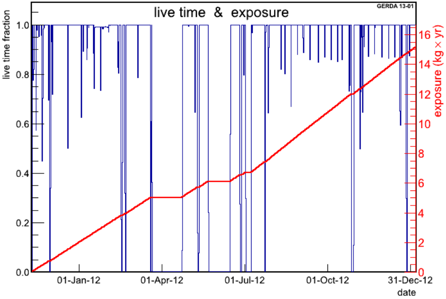
5 enriched bege in the 1-string arm (total mass: 3.6 kg)

Phase I

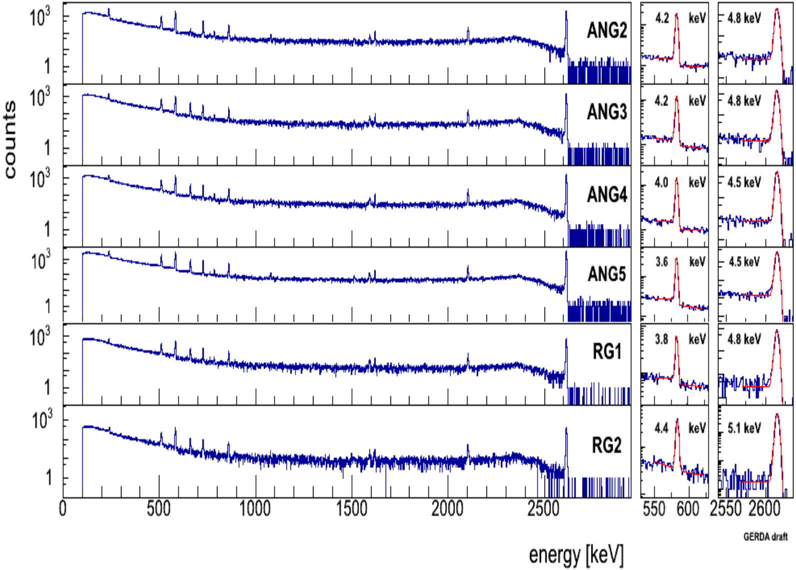
Phase I started on 11.2011!

Exposure by end 2012:
15.16 kg · yr (enr)
4.69 kg · yr (nat)

Average duty cycle: 81%

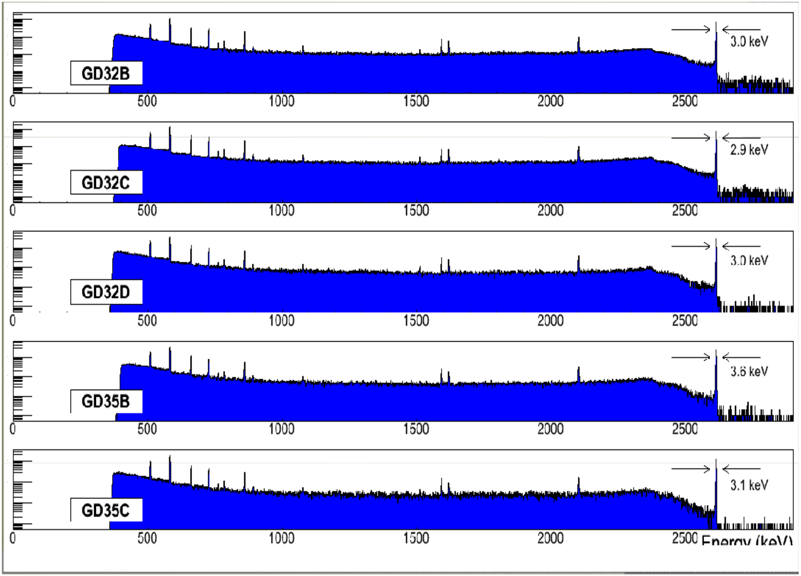


Calibrations with ^{228}Th sources - Enriched coaxial detectors



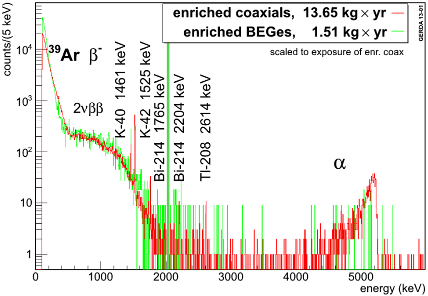
Mass weighted average for FWHM at $Q_{\beta\beta} \simeq 4.5$ keV

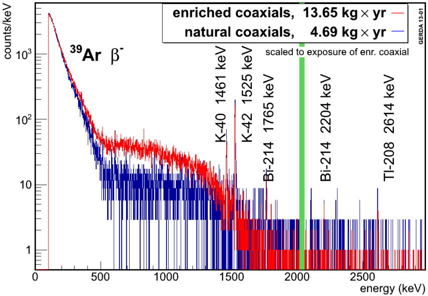
Calibrations with ^{228}Th sources - BEGe detectors



Mass weighted average for FWHM at $Q_{\beta\beta} \simeq 3.0$ keV

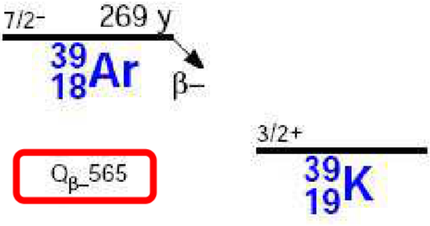
Energy spectra

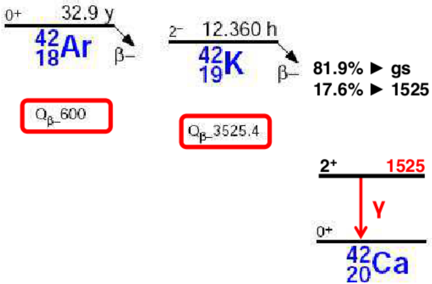




Since January 2012, we are not analyzing the data in the blind region $Q_{\beta\beta} \pm 20$ keV, to be unbiased in the background extimation. Unblinding: June/July 2013

Radioactivity of Ar isotopes

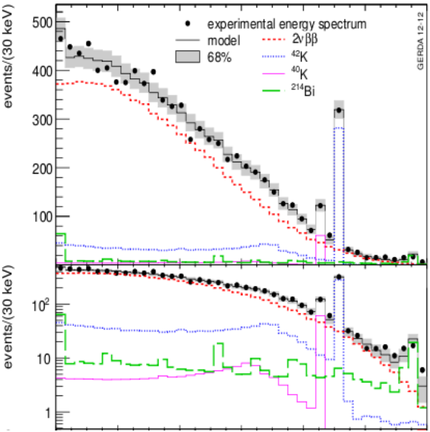




^{39}Ar activity in natural argon:
(1.01± 0.08) Bq/kg
(Benetti et al., NIM A547 (2007) 83)
Fully compatible with our data.
Not a background at $Q_{\beta\beta}$

^{42}Ar activity in natural argon:
Upper limit of 41 μBq/kg (90% C.L.)
(Ashitkov et al., arXiv:nucl-ex:0309001)
Count rate at 1525 keV 2x than expected

$^{76}Ge\ 2\nu\beta\beta$ half-life



Binned maximum likelihood

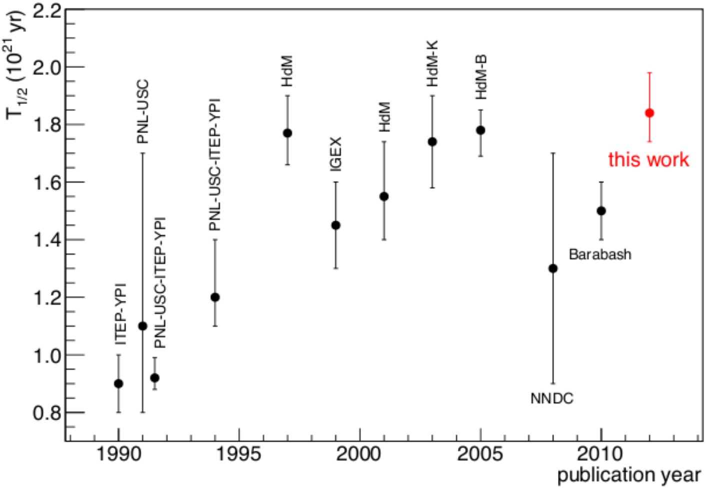
Fit range: 600-1800 keV
Exposure: 5.04 kg·yr

Best fit:
$2\nu\beta\beta$ 80%
^{42}K 14%
^{214}Bi 4%
^{40}K 2%

Integrating over all the nuisance parameters:
$$T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08}\ {}^{+0.11\ \text{syst}}_{-0.06\ \text{syst}}) \times 10^{21}\ \text{yr}$$

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

^{76}Ge $2\nu\beta\beta$ half-life: previous experiments



- Uncertainty comparable to best previous experiment (even with lower exposure)
- Good agreement with the HdM re-analysis
  HdM-K: Nucl. Instr. Meth. A 513, 596 (2003)
  HdM-B: Phys. Part. Nucl. Lett 2, 77 (2005)

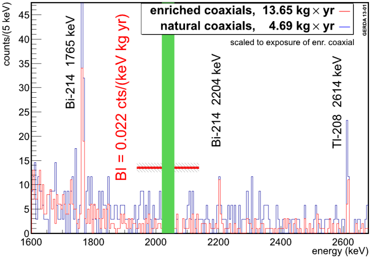
Background index around $Q_{\beta\beta}$

Background index ($Q_{\beta\beta} \pm 100$keV minus blind region → window size: 160 keV)
without pulse shape discrimination

$0.022^{+0.003}_{-0.003}$ counts/(keV·kg·yr) for enriched coaxial detectors
($0.017^{+0.003}_{-0.003}$ counts/(keV·kg·yr) excluding 1.30 kg·yr of higher background due to operations for the BEGe string insertion)
$0.041^{+0.015}_{-0.012}$ counts/(keV·kg·yr) for enriched bege detectors
$0.051^{+0.009}_{-0.008}$ counts/(keV·kg·yr) for natural detectors

Most likely from a combination of Compton of γ's from Th/U chains (^{208}Tl and ^{214}Bi), degraded β from ^{42}K, degraded α from ^{210}Po.

Enriched detectors (phase I)



B.I. (without pulse shape)

HdM : 0.11 counts/(keV · kg · yr)

IGEX : 0.17 counts/(keV · kg · yr)

Phase I exposure goal: 20 kg yr (June/July)
Expected sensitivity:
$\sim 2 \times 10^{25}$ years @ 90% C.L. (without p.s.)

Pulse shape for coaxial detectors
→ Work in progress

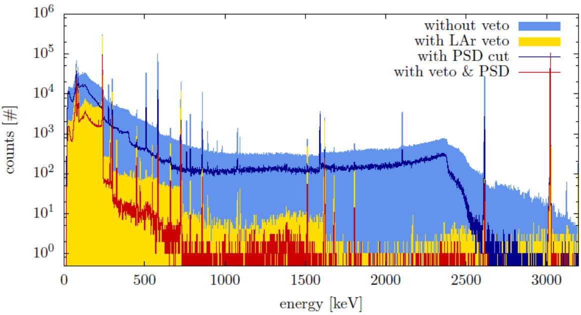
Phase II - Liquid argon instrumentation

Phase II goals: exposure 100 kg yr (20 kg of new GE detectors (BEGe)), LAr instrumentation, B.I. ~ 0.001 counts/(keV·kg·yr) Start in 2013
Expected sensitivity $\sim 15 \times 10^{25}$ yr @ 90% C.L.

Several options are being investigated for the read-out of the LAr scintillation light.

A PMT-based approach is running in LArGe (a smaller GERDA facility).

Combining the superior PSD of BEGes (Phase II detectors) with the LAr veto, we measured a suppression factor $\sim 0.5 \times 10^4$ around $Q_{\beta\beta}$ for a ^{228}Th calibration source.



Phase III: Worldwide collaboration?

The collaboration

$\sim$ 112 physicists, 18 institutions, 6 countries

Conclusions

- Phase I data taking started on 11.2011
- Data acquisition: ongoing. Current duty cycle: 81%
- Detectors are stable except for two coaxials which present LC problems
- End 2012 enriched exposure: 15.16 kg·yr
- Background is much lower than in previous experiments (HdM & IGEX): GERDA concept validated
- Fit of $2\nu\beta\beta$ spectrum with a model of $2\nu\beta\beta$, ^{42}Ar, ^{40}K and ^{214}Bi in the 600-1800 keV energy window
- Phase I completition: June/July 2013

- Phase II is already funded. R&D and testing of prototypes is ongoing.
  Key feature: detection of LAr scintillation light.

The GERDA experiment for the search of $0\nu\beta\beta$ decay in ^{76}Ge
arXiv:1212.4067 [physics.ins-det] (Eur. J. Phys C accepted)

Thank you for your attention

Backup slides

The importance of neutrinoless double beta decay

Oscillations $\Longrightarrow$ Massive neutrinos $\Longrightarrow \nu_\alpha = \sum_{i=1}^{3} U_{\alpha i} v_i$

ν_α	$=$ flavor eigenstate ν_e, ν_μ, ν_τ
U	$=$ 3x3 PMNS (Pontecorvo–Maki–Nakagawa–Sakata) mixing matrix
v_i	$=$ mass eigenstate i

Neutrinos are massive $\Longrightarrow$ new open problems

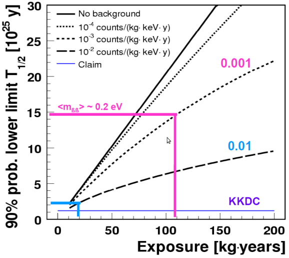
- Neutrino nature (Majorana or Dirac particle)
- Absolute mass scale

Some answers may come from the observation of Neutrinoless Double Beta ($0\nu\beta\beta$) decay

Schechter Valle theorem: $0\nu\beta\beta \Longrightarrow$ Majorana ν

Phases

- Phase I ($\sim$ 20 kg·yr) Ongoing
  Detectors from HdM & IGEX + BEGes
  $B.I. \sim$ 0.02 counts/(keV·kg·yr) (without p.s.)
  Target sensitivity: 2×10^{25} years @ 90% C.L.
- Phase II (100 kg·yr) 2013
  20 kg of new GE detectors (BEGe)
  LAr instrumentation
  $B.I. \sim$ 0.001 counts/(keV·kg·yr)
- Phase III
  Worldwide collaboration?

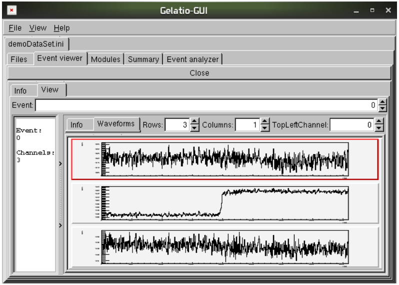


GERDA Software Framework

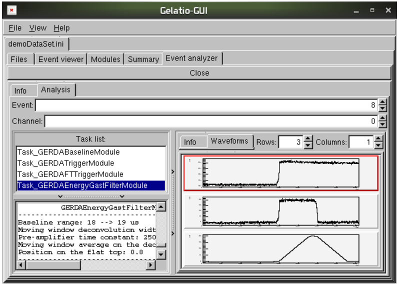
GELATIO: a general framework for modular analysis of high-purity Ge detector signals
JINST **6** (2011) P08013

- Written in C++ / ROOT
- Managing different data sources in a common way
- Modular design
- Signal processing features
- Fully integrated with a database

The graphical user interface



Event viewer



Event analyzer

GERDA and LArGe

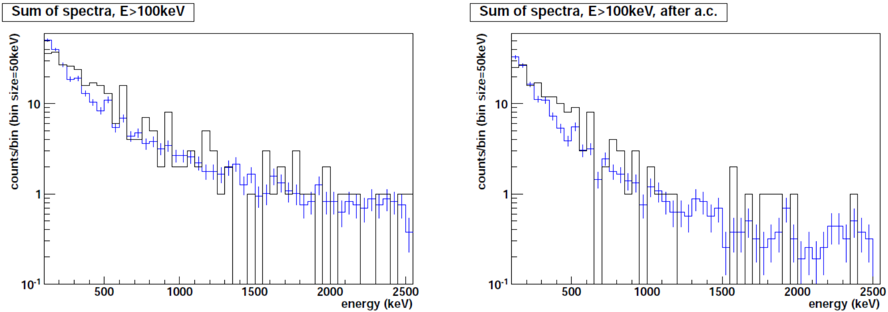
GERDA

LArGe

Warning: the scale is not the same!

Muon induced events

Spectrum of muon-induced events in Germanium
Exposure=2.09 kg·y, 3 ^{nat}Ge detectors
Black=data, Blue=Monte Carlo ... excellent agreement!



Estimate of muon veto efficiency for events which cause a signal in Ge:
$\varepsilon = 98.7\%$

Estimate of muon-induced background at $Q_{\beta\beta}$:
$B_\mu < 2.0 \times 10^{-4}$counts/(kg·keV·y) 95% CL

Background lines

isotope	energy [keV]	^{nat}Ge–dets (3.2 kg·y) tot/bck [cnt]	^{nat}Ge–dets (3.2 kg·y) rate [cnt/(kg·y)]	^{enr}Ge–dets (6.1 kg·y) tot/bck [cnt]	^{enr}Ge–dets (6.1 kg·y) rate [cnt/(kg·y)]	HdM rate [cnt/(kg·y)]
^{40}K	1460.8	85 / 15	$21.7^{+3.9}_{-3.1}$	125 / 42	$13.5^{+2.5}_{-2.2}$	181 ± 2
^{60}Co	1173.2	43 / 38	< 5.8	182 / 152	$5.1^{+3.1}_{-3.1}$	55 ± 1
	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
^{228}Ac	910.8	54 / 38	$5.0^{+3.0}_{-3.0}$	294 / 303	< 11.1	29.8 ± 1.6
	968.9	64 / 42	$6.7^{+3.8}_{-3.1}$	247 / 230	< 15.2	17.6 ± 1.1
^{208}Tl	583.1	56 / 51	< 6.5	333 / 327	< 7.6	36 ± 3
	2614.5	9 / 2	$2.1^{+1.2}_{-1.0}$	10 / 0	$1.5^{+0.7}_{-0.5}$	16.5 ± 0.5
^{214}Pb	352	740 / 630	$34.6^{+15.2}_{-12.4}$	1770 / 1688	$13.2^{+11.5}_{-7.9}$	138.7 ± 4.8
^{214}Bi	609.3	99 / 51	$14.8^{+4.9}_{-3.5}$	351 / 311	$6.2^{+4.7}_{-4.0}$	105 ± 1
	1120.3	71 / 44	$8.4^{+3.8}_{-3.4}$	194 / 186	< 6.1	26.9 ± 1.2
	1764.5	23 / 5	$5.5^{+2.0}_{-1.6}$	24 / 1	$3.6^{+0.9}_{-0.9}$	30.7 ± 0.7
	2204.2	5 / 2	$0.8^{+0.9}_{-0.7}$	6 / 3	$0.4^{+0.4}_{-0.4}$	8.1 ± 0.5