# Background Characterization for the GERDA Experiment

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Outline:

- Motivation: Search for $0\nu\beta\beta$-decay.
- Overview of the GERDA experiment.
- Background characterization with the first GERDA data.

**GER**manium **D**etector **A**rray (GERDA) experiment is designed to search for neutrinoless double beta ($0\nu\beta\beta$) decay of $^{76}$Ge

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

$0\nu\beta\beta$: (A,Z) $\rightarrow$ (A,Z+2) + $2e^-$

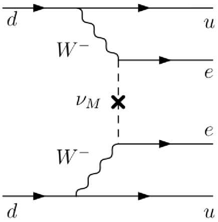
- Lepton number violation $\Delta$L = 2

  If $0\nu\beta\beta$ observed:

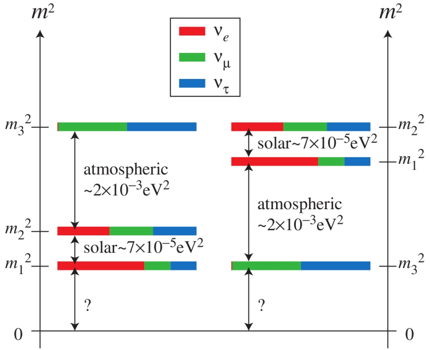
- Nature of neutrinos:
  $\bar{\nu} = \nu \Leftrightarrow$ Majorana particles
  (Schechter-Valle theorem)
- Determination of effective Majorana $\nu$ mass

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

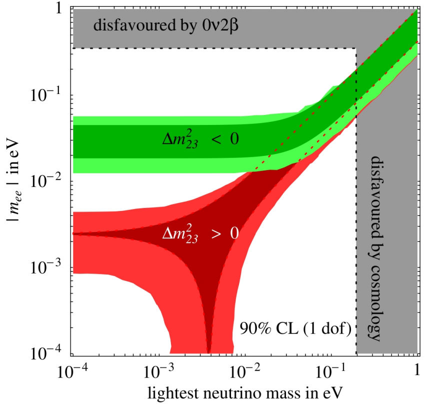
$\Rightarrow$ possible to determine absolute $\nu$ mass scale
$\Rightarrow$ possible to probe $\nu$ mass hierarchy (normal or inverted)



# Neutrino Mass Hierarchy and Effective Majorana Neutrino Mass




F. Feruglio *et al.*, Nucl. Phys. B637 (2002)




$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu} \cdot |M^{0\nu}|^2 \cdot \langle m_{\beta\beta}\rangle^2$$

Best limit $T^{0\nu}_{1/2}(^{76}Ge) > 1.9 \times 10^{25}$ y
corresponds to $|m_{ee}| < 0.35$ eV (90% C.L.)
Eur. Phys. J. A 12, 147154 (2001)

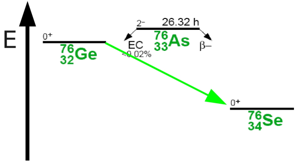
# Double Beta Decay

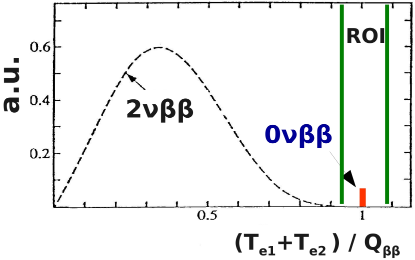
$0\nu\beta\beta$ : **(A,Z)** $\rightarrow$ **(A,Z+2)** + **2**$e^-$ $\Delta L = 2$

$2\nu\beta\beta$ : **(A,Z)** $\rightarrow$ **(A,Z+2)** + **2**$e^-$ + **2**$\bar{\nu}_e$ $\Delta L = 0$

Neutrino accompanied double beta decay ($2\nu\beta\beta$)

- ▷ Allowed in SM
- ▷ If $\beta$-decay is energetically forbidden
- ▷ 2nd order weak process
- ▷ Observed for several isotopes
  $\Rightarrow$ $T_{1/2} \sim O(10^{20}$ y)
- ▷ Experimental signal: sum energy spectrum of both electrons $\rightarrow$ continuous spectrum




**Experimental signal of $0\nu\beta\beta$:**
**peak at the Q value of double beta decay**
**$Q_{\beta\beta}(^{76}Ge) = 2039$ keV**

# Neutrinoless Double Beta Decay

$0\nu\beta\beta$-decay is a very rare process ($T_{1/2} > 10^{25}$ y)

**limit:** $T^{0\nu}_{1/2}(^{76}Ge) > 1.9 \times 10^{25}$ y (90% C.L.) Eur. Phys. J. A 12, 147154 (2001)

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sensitivity on $T_{1/2} \propto \kappa \cdot \frac{N_A}{M_A} \cdot \epsilon \cdot \sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$

⇒ Large exposure ($M \cdot t$)

⇒ High fraction of $^{76}$Ge ($\kappa$)
isotopic enrichment ∼ 86%

⇒ Low background in the ROI (b)

⇒ Good energy resolution ($\Delta E$)
HPGe: ∼0.2% @ $Q_{\beta\beta} = 2039$ keV

⇒ High signal detection efficiency ($\epsilon$)
∼ 85-95% (source = detector)

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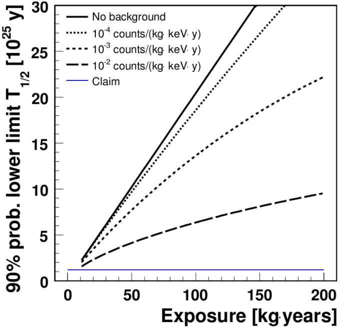
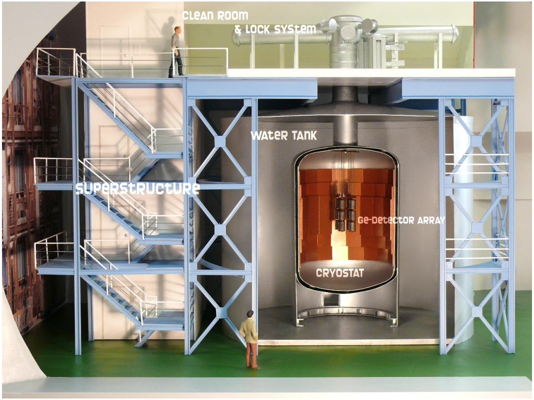


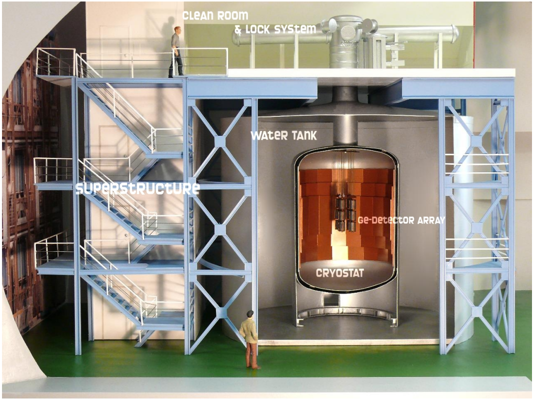

| GERDA | Phase-I | Phase-II |
|---|---|---|
| **sensitivity on the $T_{1/2}$** | $\sim 3 \times 10^{25}$ y | $\sim 1.35 \times 10^{26}$ y |
| **exposure** | 18 kg.y | 100 kg.y |
| **background index** | $10^{-2}$ counts/(keV·kg·y) | $10^{-3}$ counts/(keV·kg·y) |




**Background reduction strategy:**

- ▷ **Underground location**
- ▷ **Active muon veto**
- ▷ **Large high-purity shields**
- ▷ **Ultra-pure environment**
- ▷ **Active background rejection**

# The GERDA experiment



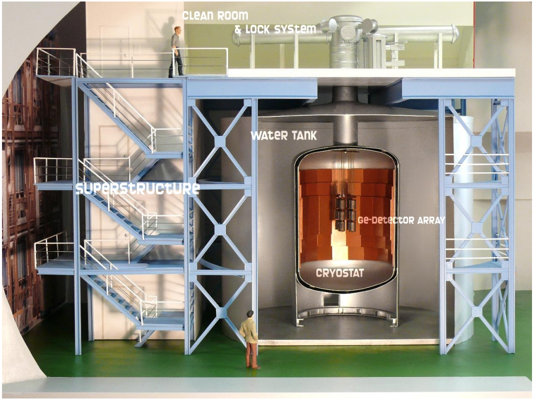

**Background reduction strategy:**

▷ **Underground location**

• at LNGS, Italy

• overburden of 1.4 km of rock above the experimental hall

• cosmic ray induced muon (neutron) flux reduced by a factor of $10^6$ ($10^3$) compared to the surface




**Background reduction strategy:**

▷ **Underground location**

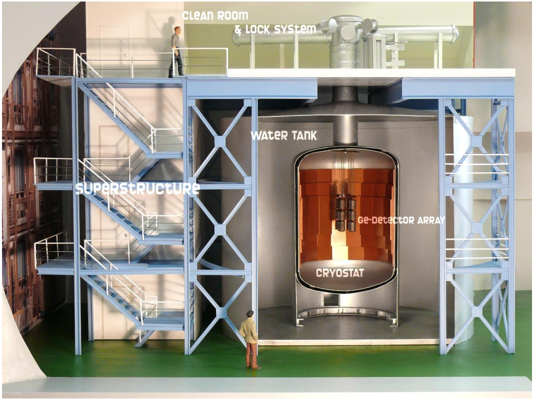
▷ **Active muon veto**

• reject the events induced by muons still reaching the setup

• photomultiplier tubes detect the Cherenkov radiation

• very high detection efficiency $\approx$ 98%

# The GERDA experiment




**Background reduction strategy:**

▷ **Underground location**

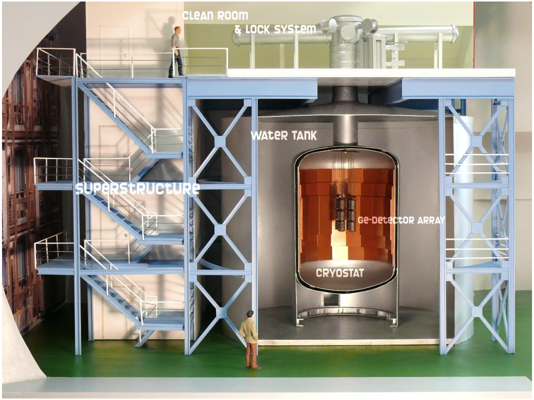
▷ **Active muon veto**

▷ **Large high-purity shields**

• Novel idea: HPGe detectors directly submerged in LAr (cooling and shielding)

• ultrapure water surrounds the LAr cryostat, shields against external radiation

# The GERDA experiment




**Background reduction strategy:**

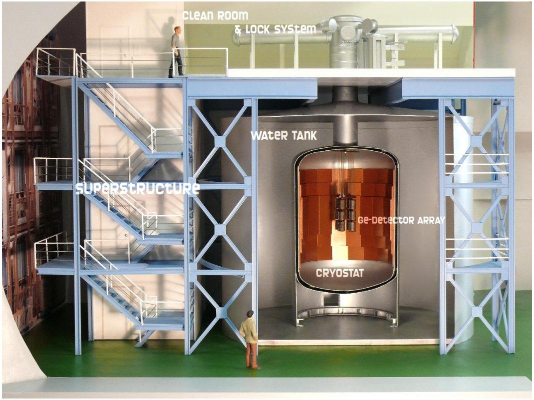
▷ **Underground location**

▷ **Active muon veto**

▷ **Large high-purity shields**

▷ **Ultra-pure environment**

• Minimal amount of screened material in the vicinity of the detectors




**Background reduction strategy:**

▷ **Underground location**

▷ **Active muon veto**

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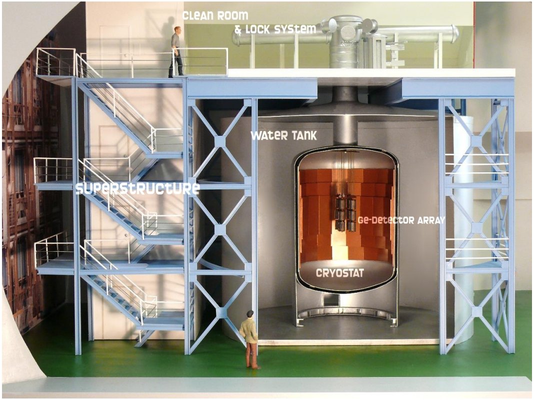
• analysis methods to suppress the remaining background events, e.g. Pulse Shape Analysis

# The GERDA experiment




**Background reduction strategy:**

▷ **Underground location**

▷ **Active muon veto**

▷ **Large high-purity shields**

▷ **Ultra-pure environment**

▷ **Active background rejection**

**Data-taking started on July 2010 for the commissioning of the experiment.**

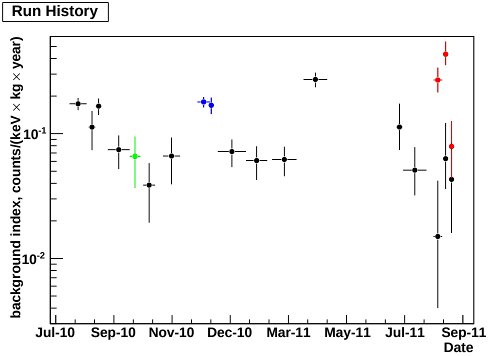
# First data

Data-taking in the commissioning phase: July 2010 - October 2011

p-type coaxial HPGe detectors from previous experiments deployed

Several data-taking runs with different configurations performed

⇒ find the conditions to achieve the lowest possible background index



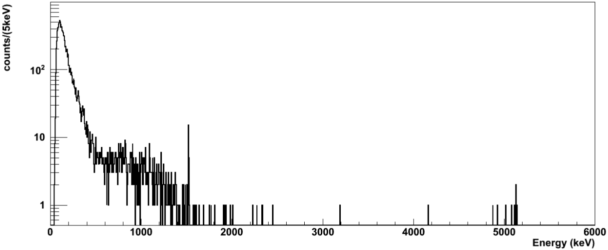

B.I. in the commissioning runs:

▷ significantly better than for any other previous experiment

▷ ∼ 5 times higher than the Phase-I goal of $10^{-2}$ counts/(keV×kg×year)

# Background Characterization

*Measured background spectrum, 1-25 July 2011, exposure: 106.7 kg×day*




▷ Isotopically enriched p-type coaxial HPGe detectors

▷ Resolution ∼2% at 2.6 MeV

▷ Spectrum obtained after muon-veto cut applied

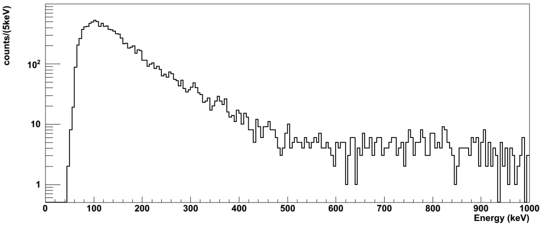
- Model the origin of background components
- Verify the model by simulations
- Understand the background

& identify different contributions at the ROI (around $Q_{\beta\beta} = 2039$ keV)

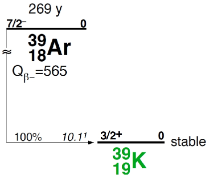
# Background Characterization

## Low-energy part of the Background Spectrum

*Measured background spectrum, 1-25 July 2011, exposure: 106.7 kg×day*




- ▷ Dominant background at low-energy ⇒ $^{39}$Ar $\beta$-decay
- ▷ Cosmogenic origin: $^{40}$Ar(n,2n)$^{39}$Ar & present in LAr
- ▷ Pure $\beta$-emitter:




Below the Q-value of $0\nu\beta\beta$-decay

$$Q_\beta = 565 \text{ keV} < Q_{\beta\beta} = 2039 \text{ keV}$$

Analysis:

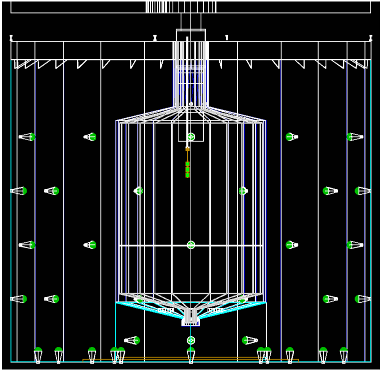
- ▷ Learn about detector properties, e.g. dead layers etc.
- ▷ Cross-check the specific activity of $^{39}$Ar

- Simulation in MaGe:

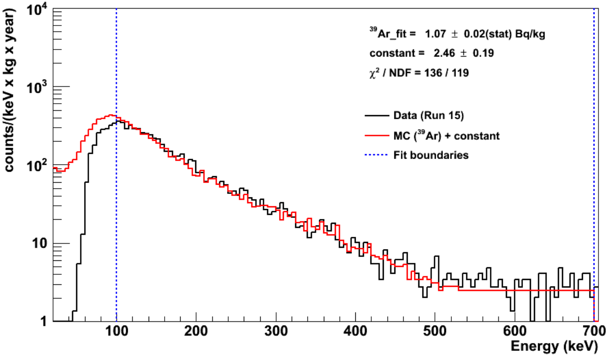
  ▷ C++ Monte Carlo framework, based on Geant4.

  ▷ Joint development of Majorana and Gerda collaborations.
- Detailed GERDA setup was already implemented
- Detailed detector geometry is implemented for $^{39}$Ar $\beta$-decay simulation.
- Decays are generated in LAr surrounding the detectors

**GERDA Geometry in MaGe**



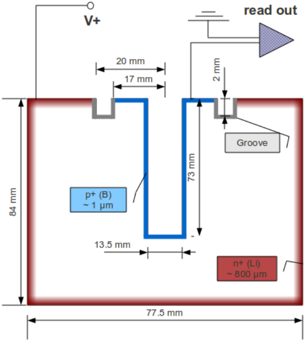
$\chi^2$-fit of the experimental spectrum with the simulated $^{39}$Ar $\beta$-decay spectrum plus a flat contribution performed in 100 keV - 700 keV window:




$$\chi^2 = \sum_{i=1}^{N} \frac{(d_i - f_i)^2}{\sigma_{d_i}^2 + \sigma_{f_i}^2 \cdot \left(\frac{d_i}{f_i}\right)^2}$$

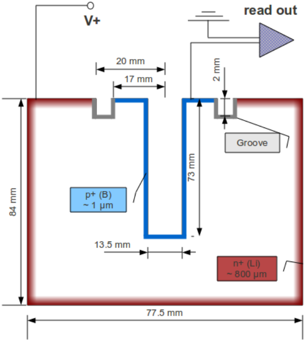
**$^{39}$Ar specific activity derived from the fit: 1.07 ± 0.02(stat) Bq/kg.**

Geometry of p-type coaxial HPGe detectors



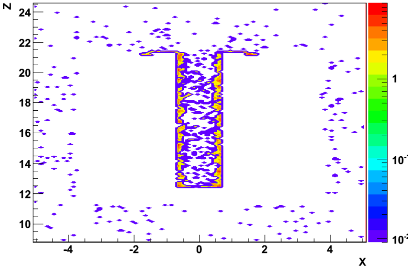

p+: B-implanted contact inside (thin DL: 1 $\mu$m)
n+: Li-drifted contact outside (thick DL: 800 $\mu$m)
High voltage on the outer contact, read out the inner contact

Geometry of p-type coaxial HPGe detectors




p+: B-implanted contact inside (thin DL: 1 $\mu$m)
n+: Li-drifted contact outside (thick DL: 800 $\mu$m)
High voltage on the outer contact, read out the inner contact

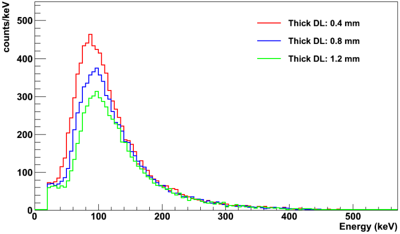
primary vertex positions of decays that led to energy deposit in the active volume of the detector




Most of the signal is due to the decays taking place close to the regions with thin dead layer

mean free path of 600 keV $\beta$'s in Ge: $\sim$ 800 $\mu$m

$\Rightarrow$ Realistic DL model is important for simulation of $^{39}$Ar $\beta$-decay




Strong dependence on the DL model (below ≈150 keV)

Specific activity for:
0.4 mm thick DL ⇒ $0.99 \pm 0.01$(stat)
1.2 mm thick DL ⇒ $1.15 \pm 0.02$(stat)

Specific activity of $^{39}$Ar in GERDA: ($1.07 \pm 0.02$(stat) $\pm 0.07$(sys)) Bq/kg.

in good agreement with the literature value

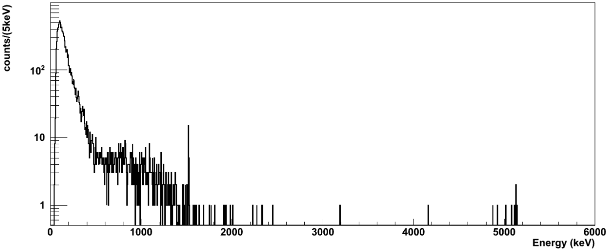
Specific activity of $^{39}$Ar in WARP: ($1.01 \pm 0.08$) Bq/kg. Nucl. Instr. and Meth. A 574 (2007) 83-88

▷ $^{39}$Ar is the dominant background in the low-energy region (upto the Q-value)

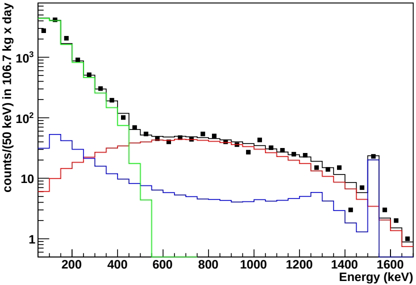
# Background Characterization

Decomposition of the observed background spectrum

*Measured background spectrum, 1-25 July 2011, exposure: 106.7 kg×day*




- ▷ Isotopically enriched p-type coaxial HPGe detectors
- ▷ Resolution ∼2% at 2.6 MeV
- ▷ Spectrum obtained after muon-veto cut applied




Total background spectrum decomposed into contributions from:

green: $^{39}$Ar $\beta$-decay spectrum (normalization for A = 1.01 Bq/kg)

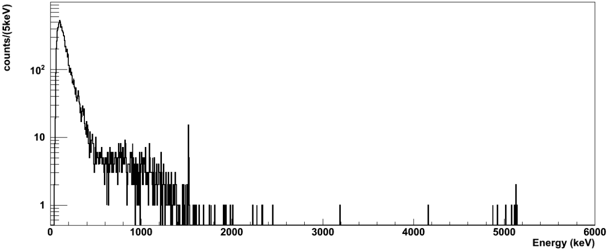
red: $^{76}$Ge $2\nu\beta\beta$-decay spectrum (normalization for $T_{1/2} = 1.74 \times 10^{21}$ y)

blue: $^{42}$K spectrum (relatively normalized to match the peak counting rate)

# Background Characterization

## Background contribution around $Q_{\beta\beta}$

*Measured background spectrum, 1-25 July 2011, exposure: 106.7 kg×day*




- ▷ Isotopically enriched p-type coaxial HPGe detectors
- ▷ Resolution ~2% at 2.6 MeV
- ▷ Spectrum obtained after muon-veto cut applied

The origin of the background counts observed around the $Q_{\beta\beta}$ is under investigation.

Some possible background contributions:

- $^{42}$K $\beta$-decay ($Q_\beta = 3525$ keV)
  decay product of $^{42}$Ar present in LAr,
  we observe the most intense (18.1%) $\gamma$-line at 1525 keV
- natural decay chains ($^{226}$Ra, $^{232}$Th)
  distant sources in the setup with U/Th contamination
- $\alpha$-decays at detector surfaces
  $^{222}$Rn-daughters or $^{210}$Pb contamination on surface
- cosmic ray muons

# Summary

- Data-taking for the commissioning of GERDA: July 2010 - October 2011

  ▷ Understanding of the background major importance

- B.I. higher than Phase-I goal but significantly lower than previous experiments

- Analysis of the commissioning data

  ▷ Background spectrum has been modeled

  ▷ Expectations from simulations and measurements agree very well in the energy region from 100 keV to 1800 keV.

- Origin of background counts observed around $Q_{\beta\beta}$ under investigation.

- GERDA Phase-I started on November 2011.