The GERDA experiment: status and future plans

Paolo Zavarise

Università dell'Aquila
(PhD student in Physics)

INFN-LNGS, GERDA Collaboration

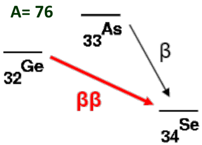
VULCANO WORKSHOP, June 1st, 2012

OUTLINE:

- GERDA motivations
- GERDA status
- GERDA future plans

GERDA motivations

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



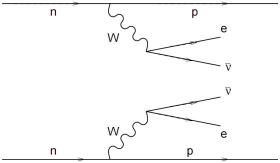
$Q_{\beta\beta} = 2039$ keV

$2\nu\beta\beta$

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

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

Observed.



$0\nu\beta\beta$

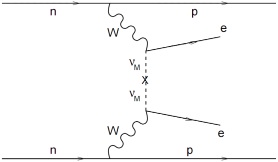
$(Z, A) \rightarrow (Z+2, A) + 2e^-$

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

Observed?

Schechter Valle: $0\nu\beta\beta \Rightarrow$ Majorana ν

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 mass of electron neutrino

information on the absolute mass scale!

Part of Heidelberg-Moscow Collaboration claimed evidence for $0\nu\beta\beta$ observation of ^{76}Ge (PL B586 (04) 198)

$$T_{1/2} = 1.2(0.7 - 4.2) \times 10^{25} y$$

(3σ range)

First goal of GERDA: 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 is required $\Longrightarrow$ 86% ^{76}Ge

Advantages

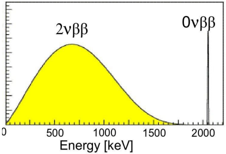
- 4π solid angle
- Industrial techniques and facilities available to enrich the material
- High purity
- Excellent energy resolution

Disadvantages

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

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

$2\nu\beta\beta$: energy range 0 to $Q_{\beta\beta}$ (a part of the released energy is carried away by neutrinos)
$0\nu\beta\beta$: constant energy $Q_{\beta\beta}$



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)

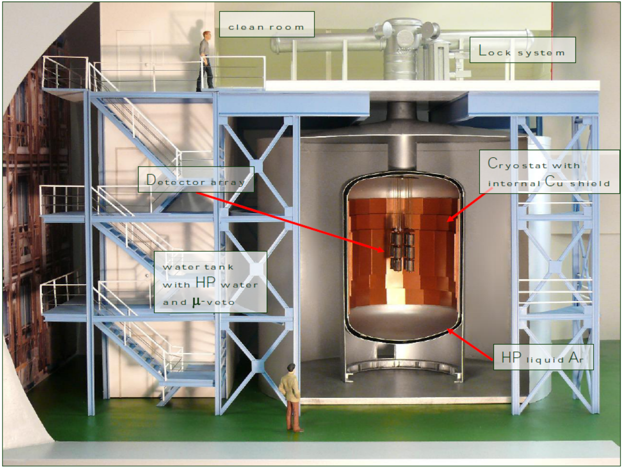
Low background $\Longrightarrow$ better sensitivity!

GERDA @ LNGS

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

Suppression of μ-flux$> 10^6$

The GERDA setup



Main features

Water tank
$\varnothing = 10m$
$h = 8.9m$
$V_{water} = 580m^3$
The water tank acts as an active Cherenkov veto

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

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

Naked detectors in LAr!
LAr $\rightarrow$ Passive shielding, Cooling, Active veto detecting scintillation light (Phase II)

The GERDA detectors configuration

Detectors are organized in strings - Low mass holders
8 enriched detectors + GTF112 in the 3-string arm.
Total mass of enriched detectors: ~ 17.7 kg
ANG detectors come from HdM experiment, RG detectors come from IGEX

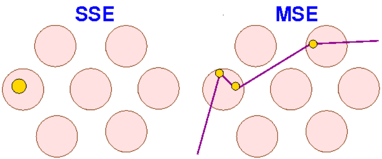
Events identification

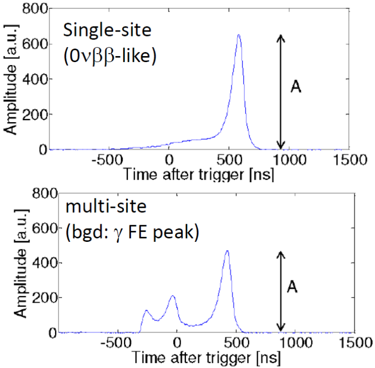
How to understand the nature (signal or background?) of events around $Q_{\beta\beta}$?

- 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



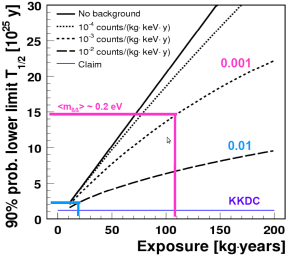


Second step approaches:

- Anti-coincidence of detectors
- Pulse shape analysis

GERDA Roadmap

- Phase I (15 kg· yr) Started
  Detectors from HdM & IGEX
  $B \sim 0.01$ counts/(keV·kg·yr)
- Phase II (100 kg· yr) 2013
  + New GE detectors (BEGe, $\sim$ 20 kg)
  $B \sim 0.001$ counts/(keV·kg·yr)
- Phase III
  Worldwide collaboration?

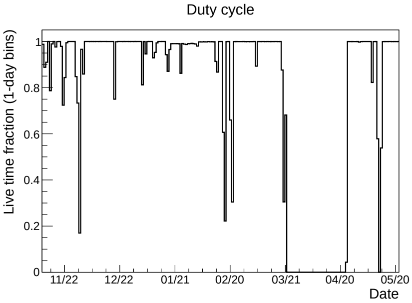


Phase I started on 1.11.11!

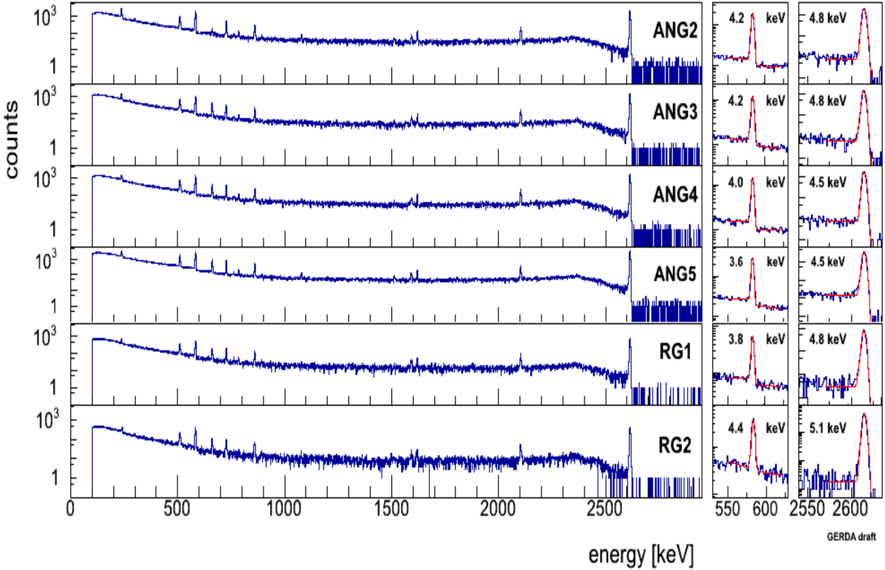
Status (up to May, 22nd)

Total time: 194.6 days
Livetime : 152.5 days
Duty cycle: 78%

Exposure:
6.10 kg· yr (enr)
3.17 kg· yr (nat)



Phase I detectors resolution (FWHM) - ^{228}Th sources

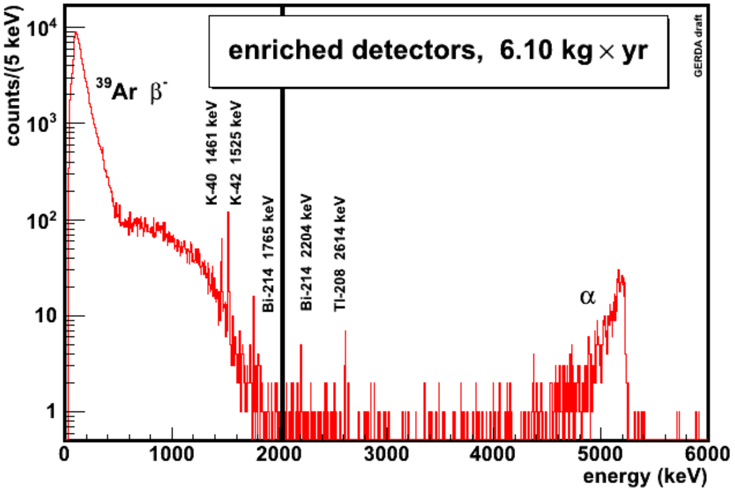


Energy calibration is performed by using 7 prominent lines, in the window 511keV-2614keV

Only 6 enriched detectors considered in the analysis (total mass: 14.6 kg)

Two detectors present stability (LC) problems

Enriched detectors - sum of spectra



Black band: blind region ($Q_{\beta\beta} \pm 20 keV$). Since January 2012, we are not analyzing the data in the blind region, to be unbiased in the background extimation.

Radioactivity in argon

We are seeing the effects of two radioactive Argon isotopes: ^{39}Ar and ^{42}Ar

$^{39}\mathrm{Ar} \xrightarrow{\beta^-, 269yr, Q=565keV} {}^{39}\mathrm{K}$
Expected, clearly visible, and not a background for GERDA!

$^{42}\mathrm{Ar} \xrightarrow{\beta^-, 32.9yr, Q=600keV} {}^{42}\mathrm{K} \xrightarrow{\beta^-, 12.36h, Q=3525keV} {}^{42}\mathrm{Ca}$
The 1524.7keV line arises from the ^{42}K decay (BR 17.6%). Rate 2x than expected! These photons are not a concern, but the β emitted in the decay of ^{42}K is a possible background!

Treating the ^{42}K problem

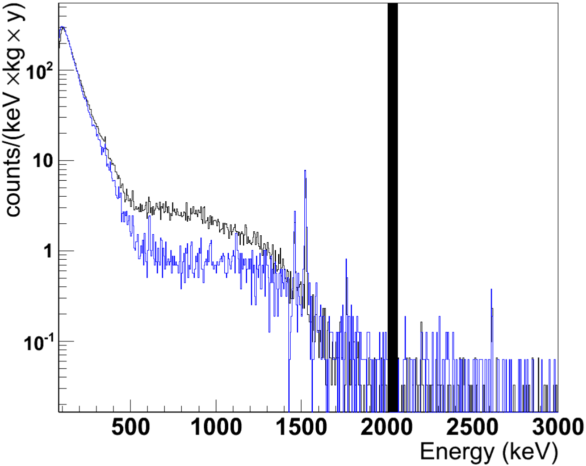
- The initial decay $^{42}\mathrm{Ar} \rightarrow {}^{42}\mathrm{K}$ produces the daughter in a charged state, which can drift close to the detectors under the action of electric fields.
- Background source only if ^{42}K comes very close to the detectors.
- A string of detetors can be surrounded by a Cu shield, the minishroud, ($\phi = 11.5$cm, thickness=60μm) to limit the drift of ions

Enriched detectors inside the minishrouds

Natural and Enriched detectors

Blue: natural detectors

Black: enriched detectors

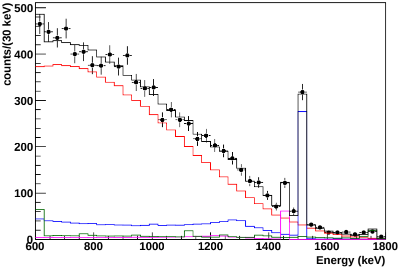


$^{76}Ge\ 2\nu\beta\beta$ spectrum is obiouvsly more significant in enriched detectors!

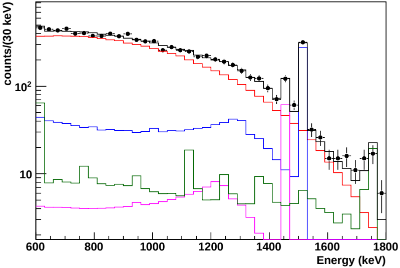
Spectrum decomposition

Model fit where the $2\nu\beta\beta$ the dominant component.
(Component spectra from Monte Carlo simulations, full GERDA geometry, GEANT4)

Linear scale



Log scale



Legend: $2\nu\beta\beta$ ^{42}K ^{40}K ^{214}Bi Model sum — Black dots: data

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

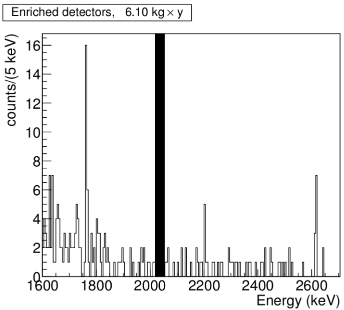
Background index
($Q_{\beta\beta} \pm 200keV$ minus blind region and ^{214}Bi line $\rightarrow$ window size: 350 keV)

$0.020^{+0.006}_{-0.004}$ counts/(keV·kg·yr) for enriched detectors

$0.048^{+0.010}_{-0.010}$ counts/(keV·kg·yr) for natural detectors

Design goal of Phase I (0.01) not quite reached, but greatly improved (by a factor of 6) with respect to Heidelberg-Moscow

Most likely from a combination of Compton continuum from Th/U, residual ^{42}K, degraded α, cosmogenic isotopes (^{60}Co, ^{68}Ge)



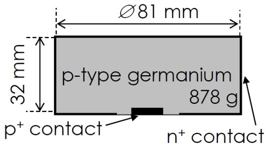
Counting rate @ 2614

HdM :$\sim 16.5 \pm 0.5$ counts/(kg·yr)
GERDA:$\sim$ 1.6 ± 0.5 counts/(kg·yr)

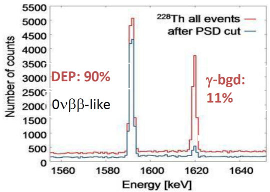
10x reduction!

Phase II - BEGe detectors

Phase II detectors have been chosen to ensure a superior PSD. We tested the point-contact BEGe from Canberra, and found them OK for Phase II - JINST 4 P10007



PSD based on A/E ratio

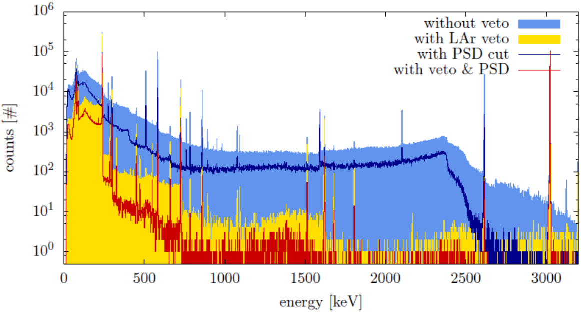


BEGe production and testing ongoing!

Phase II - Liquid argon instrumentation

We are testing a PMT-based approach to the LAr instrumentation for Phase II in LArGe (a smaller GERDA facility)

Combining the superior PSD of BEGe (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.

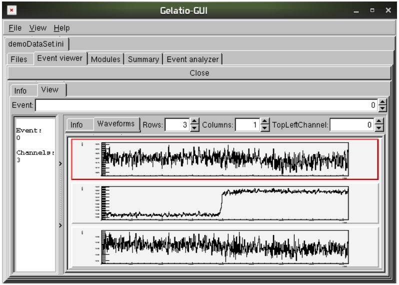


GERDA Software Framework

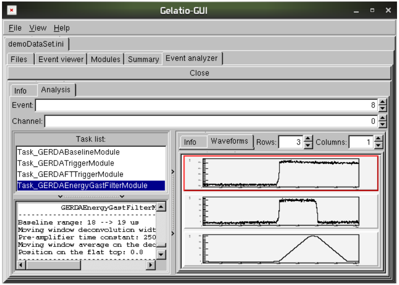
GELATIO: a general framework for modular analysis of high-purity Ge detector signals
JINST **6** (2011) P08013

- 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

The collaboration

∼ 115 physicists, 19 institutions, 7 countries

Conclusions

- Phase I data taking started on 1.11.2011
- Data acquisition: ongoing. Current duty cycle: 78%
- Detectors are stable except for two enriched detectors which present LC problems
- Today enriched exposure: 6.10 kg·y
- Current background index: 0.020 counts/(keV·kg·yr)
- Background seems much lower than in previous experiments (HdM & IGEX): GERDA concept validated
- $2\nu\beta\beta$ spectrum well visible
- A model with $2\nu\beta\beta$, ^{42}Ar, ^{40}K and ^{214}Bi well fits the 600-1800 keV energy window
- Phase I completition: Spring 2013?

- Phase II in advanced state of preparation. Features: BEGe detectors (enhanced PSD), Veto by LAr scintillation light...

Thank you for your attention.