Results and Perspectives of GERDA: on the way to Phase II

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NOW 2014
Conca Specchiulla 8-14 September 2014
GERDA collaboration

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

16 Institutions ~100 members
Located in Hall A @ LNGS
GERDA Installations

- Clean room with lock (old version) & clean bench
- Muon & cryogenic infrastructure
- Control rooms
- Water plant & radon monitor
- Ge-76 array (as larger)
- Detector = source
- LAr cryostat, Ø4m, with internal Cu shield
- Water tank, Ø10m, part of µ-veto detector
Pictures from GERDA

8/09/2014
Data taking:
Nov 2011-June 2013

Goal:
Scrutinize claimDemonstrate Bi

Exposure:
21.6 kg y
**Observation of $2\nu\beta\beta$**


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**Gerda Result**

- **Exposure**: 5kg·y
- **Model**: 6 independent models for the 6 detectors (5 x 6=30 detector parameters)
- **Half-life**: $T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08 \text{ fit}} \pm 0.11 \text{ syst}) \times 10^{21} \text{ yr}$
- **Background**: from 3 sources: $^{42}\text{K}, ^{40}\text{K}, ^{214}\text{Bi}$ ($\gamma$-lines used for normalization)
  - $^{42}\text{K}$: homogeneously distributed
  - $^{40}\text{K}$ & $^{214}\text{Bi}$: close sources
- **Detections**: Active masses and enr. factors are nuisance parameters in the fit.

**$\beta\beta$ spectrum**: 8796 events

**Model of the residual background**: 80% $2\nu\beta\beta$, 14% $^{42}\text{K}$, 3.8% $^{214}\text{Bi}$, 2% $^{40}\text{K}$

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8/09/2014

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GERDA vs previous measurements of $T_{1/2}^{2\nu}$

$$T_{1/2}^{2\nu} = \left( 1.84^{+0.09}_{-0.08 \text{ fit}} ^{+0.11}_{-0.06 \text{ syst}} \right) \cdot 10^{21} \text{ yr} = \left( 1.84^{+0.14}_{-0.10} \right) \cdot 10^{21} \text{ yr}$$

- GERDA result consistent with HdM-B
  $$T_{1/2}^{2\nu} = 1.78^{+0.07}_{-0.09} \cdot 10^{21}$$

- Thanks to low BI reached comparable sensitivity with $\sim 1/10$ exposure

- $2\nu\beta\beta$ results will improve with
  - New measurement of coax active volumes
  - Include larger statistics (already available)
$0\nu\beta\beta$ Search – Blinded analysis: events in ±20 keV around $Q_{\beta\beta}$ not reconstructed

$\rightarrow$ FWHM @ $Q_{\beta\beta} = 4.8$ keV

$\rightarrow$ FWHM @ $Q_{\beta\beta} = 3.2$ keV

GTF 112, 3.13 kg x yr
Main Contamination in COAX (with large variations among detectors):
• $\alpha$ contamination from $^{210}$Po.
• contamination at time of refurbishment mostly on thin p+ contact
• $^{210}$Po decaying away ($t_{1/2}=138$ d)
• BEGes much cleaner in $^{210}$Po (> factor 10) than COAX
Background model predictions vs data in 260 keV range around $Q_{\beta\beta}$

**Minimal model**
- The model reproduces a flat background around $Q_{\beta\beta}$ (data still blinded)
- No $\gamma$-lines visible in the 30 keV range around the $Q_{\beta\beta}$
  $\rightarrow$ spectra can be fitted with a flat background apart from $^{214}$Bi lines at 2104 keV and 2119 keV

**Maximal model: Minimal +**

Pulse Shape Discrimination (PSD) to discriminate \( \beta\beta \)-like (SSE) to \( \gamma \)-like (MSE) events

Different weighting potentials for Coax and BEGe

COAX: Artificial Neural Network (ANN) estimator used as PSD parameter

BEGe: Amplitude of Current/Amplitude of Charge Pulse (A/E) is the PSD parameter
PSD efficiencies experimentally determined @Q_{ββ} & for 2νββ events (1 MeV < E < 1.5 MeV) from calibration (Double Escape Peak of 2.6 MeV line)

<table>
<thead>
<tr>
<th></th>
<th>ε_{2νββ}</th>
<th>ε_{0νββ}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coax</td>
<td>0.85 ± 0.02</td>
<td>0.90 ±0.05 -0.09</td>
</tr>
<tr>
<td>BEGe</td>
<td>0.91 ± 0.05</td>
<td>0.92 ± 0.02</td>
</tr>
</tbody>
</table>
Unblinded counts & efficiencies

\[ T_{1/2}^{0\nu} = \frac{\ln 2 \cdot N_A}{m_{enr} \cdot N_{0\nu}^{0\nu}} \cdot \mathcal{E} \cdot \epsilon \]

\[ \epsilon = f_{76} \cdot f_{av} \cdot \epsilon_{fep} \cdot \epsilon_{psd} \]

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{data set} & \mathcal{E} [\text{kg yr}] & \langle \epsilon \rangle & \text{bkg} & \text{BI} \uparrow \text{)} & \text{cts} \\
\hline
\text{without PSD} & & & & & \\
\text{golden} & 17.9 & 0.688 \pm 0.031 & 76 & 18 \pm 2 & 5 \\
\text{silver} & 1.3 & 0.688 \pm 0.031 & 19 & 63_{-14}^{+16} & 1 \\
\text{BEGe} & 2.4 & 0.720 \pm 0.018 & 23 & 42_{-8}^{+10} & 1 \\
\hline
\text{with PSD} & & & & & \\
\text{golden} & 17.9 & 0.619_{-0.070}^{+0.044} & 45 & 11 \pm 2 & 2 \\
\text{silver} & 1.3 & 0.619_{-0.070}^{+0.044} & 9 & 30_{-9}^{+11} & 1 \\
\text{BEGe} & 2.4 & 0.663 \pm 0.022 & 3 & 5_{-3}^{+4} & 0 \\
\hline
\end{array}
\]

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

- Bckgrd Rej $_{PSD}^{\text{BEGe}} \approx 87\%$
- Bckgrd Rej $_{PSD}^{\text{Coax}} \approx 43\%$

In 230 keV @\(Q_{\beta\beta}\) ± 5 keV

Expected bckgd only

8/09/2014

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Performed Profile Likelihood fit of the 3 data sets
- B+S: described by constant term + Gaus(\(Q_{\beta\beta}, \sigma_E\))
- 4 free parameters in the fit \(B_{\text{gold}}, B_{\text{silv}}, B_{\text{BEGe}}, 1/ T_{1/2}^{0\nu}\)
- Systematics folded in

**Frequentist approach**
Best fit: \(N^{0\nu} = 0\)
\(N^{0\nu} < 3.5\) cts @ 90% C.L.
\(T_{1/2}^{0\nu} > 2.1 \times 10^{25}\) yr @ 90% CL
Median sensitivity:
\(T_{1/2}^{0\nu} > 2.4 \times 10^{25}\) yr

**Bayesian approach**
Flat prior for \(1/T_{1/2}^{0\nu}\)
Best fit: \(N^{0\nu} = 0\)
\(T_{1/2}^{0\nu} > 1.9 \times 10^{25}\) yr @ 90% CI
Median sensitivity:
\(T_{1/2}^{0\nu} > 2.1 \times 10^{25}\) yr
For $T_{1/2}^{0ν} = 1.19 \times 10^{25}$ yr

Expected Signal (after PSD): $5.9 \pm 1.4$ cts in $\pm 2\sigma$

Expected Bckgd (after PSD): $2.0 \pm 0.3$ cts in $\pm 2\sigma$

Observed: 3.0 (0 in $\pm 1\sigma$)

From profile likelihood
Assuming H1 true $\rightarrow$

$P(N^{0ν}=0) = 1\%$

Comparing
H1: Claimed signal
H0: Background only

Bayes factor
$P(H1)/P(H0)=0.024$

(uncertainties on claim included)

Claim poorly credible
## Status of experimental searches

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$T^{2\nu}_{1/2}$ (10$^{19}$ y)</th>
<th>$T^{0\nu}_{1/2}$ (10$^{24}$ y)</th>
<th>$&lt;m_{\beta\beta}&gt;$ (meV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{48}$Ca</td>
<td>$4.4 \pm 0.5$ (stat) $\pm 0.4$ (syst)</td>
<td>$&gt;0.058$</td>
<td>3515-14133</td>
</tr>
<tr>
<td>$^{76}$Ge</td>
<td>$1.78^{+0.07}_{-0.09}$</td>
<td>$22.3^{+4.4}_{-3.1}$</td>
<td>400</td>
</tr>
<tr>
<td>$^{76}$Ge</td>
<td>$184 \pm 90$ (stat) $\pm 11$ (syst)</td>
<td>$&gt;21.0$</td>
<td>201-638</td>
</tr>
<tr>
<td>$^{82}$Se</td>
<td>$9.6\pm0.1$ (stat) $\pm 1.0$ (syst)</td>
<td>$&gt;0.32$</td>
<td>884-2631</td>
</tr>
<tr>
<td>$^{96}$Zr</td>
<td>$2.35 \pm 0.14$ (stat) $\pm 0.16$ (syst)</td>
<td>$&gt;0.0092$</td>
<td>4207-15139</td>
</tr>
<tr>
<td>$^{100}$Mo</td>
<td>$0.716 \pm 0.001$ (stat) $\pm 0.054$ (syst)</td>
<td>$&gt;1.0$</td>
<td>334-946</td>
</tr>
<tr>
<td>$^{116}$Cd</td>
<td>$2.88 \pm 0.04$ (stat) $\pm 0.16$ (syst)</td>
<td>$&gt;0.17$</td>
<td>1300-2440</td>
</tr>
<tr>
<td>$^{130}$Te</td>
<td>$70 \pm 9$ (stat) 11 (syst)</td>
<td>$&gt;2.8$</td>
<td>296 – 773</td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>$217.2 \pm 1.7$ (stat) $\pm 6$ (syst)</td>
<td>$&gt;26$</td>
<td>140-280</td>
</tr>
<tr>
<td>$^{150}$Nd</td>
<td>$0.911 \pm 0.025$ (stat) $\pm 0.063$ (syst)</td>
<td>$&gt;0.018$</td>
<td>2622-5678</td>
</tr>
</tbody>
</table>
GERDA II Expected Sensitivity

Assumed E resolution: $\Delta E = 4$ keV

KK Claim: 440 meV

GERDA I lower limit range: 200-400 meV

Expected GERDA II lower limit range: 90 meV

Reach a $B_\text{l} \sim 10^{-3}$ cts/(keV· kg· yr) at $Q_{\beta\beta}$ (±200 keV ROI)

Reach $T^{0\nu}_{1/2} \sim 1.5 \cdot 10^{26}$ yr (120 kgy exposure) $\Rightarrow <m_{\beta\beta}> \leq 0.09$-0.15 eV

From Dell'Oro, Marcocci, Vissani, hep-ph/1404.2616v1
GERDA Strategy to improve $T_{1/2}$ limits

- Increase $^{\text{enriched}}\text{Ge mass (} \sim 40 \text{ kg in total)}$ 21 kg in form of Ge-BEGe detectors
- $\rightarrow$ enhanced PSD to pinpoint $\beta\beta$ events (Single Site) vs residual $\gamma$ events (Multi Site)

- Reduce radioactivity of Ge holders and mechanical structures
- New Ge readout electronics with closer FE devices in die for improved FWHM
- LAr as active media (active detector) and not only as passive shield
- $^{42}\text{K bkgd: Transparent Nylon Mini Shroud (NMS)}$ coated with WLS (instead of Cu opaque) surrounding each BEGe detector string.
GERDA Phase II

Phase I: 13 kg of enrGe COAX Detectors
3 kg of enrBEGe Detectors w. enhanced PSD

Phase II: 18 kg of enrGe COAX Detectors
21 kg of enrGe BEGe Detectors w. enhanced PSD
Readout of Liquid Argon Scintillation Light

Strategy:

Wide angle eye: 16 PMTs
Closer eye: Fiber Shroud readout by SiPMs

Expected: Suppression factor ~10 for $^{214}\text{Bi}$ and $>>10$ for $^{232}\text{Th}$ events

Top/Botton: PMTs

TOP: 9 PMTs
CU shroud 1
h: 60 cm
diam: 49 cm

MIDDLE
h: 100 cm,
diam: 47 cm
Dense curtain of scintillating fibers readout by SiPMs

BOTTOM: 7 PMTs
CU shroud 2
h: 60 cm
diam: 49 cm
42K background mitigation by Nylon Mini Shroud and LAr veto

232Th background reduction by LAr veto & PSD

Measured 42K background reduction:
1BE Ge in Nylon Mini Shroud (NMS) & PMTs & PSD
$10^2$ to $10^3$
Ge detectors holders and Front End (FE) Electronics

- Holders: Si plates instead of Cu (improved radiopurity)
- Upgraded Circuit (based on commercial CMOS selected for cryogenic applications.
- Phase II FE: FE Devices (JFET in die Feedback R and C) onto the Si Plate
- Phase I FE: On CSA PCBs at 80 cm distance from bottom detector

Achieved in Phase II Tests
- FWHM: 2.6 keV @ 2.6 MeV
- Electronic Noise: 0.9 keV
- FWHM of PSD Parameter: ~ 1%
- Survival Fraction of Compton Continuum @Q_{\beta\beta} after PSD Cut ~ 50%
What Next GERDA II?

- Majorana Demonstrator at SURF (Sanford Underground Facility) is in advanced stage of construction. Operation of the First String is expected soon.
- It consists of 40 kg of Ge BEGe/PIN Point Detectors 30 kg are $^{enr}Ge$.
- The goal of the demonstrator is to show that the chosen technique (operate detectors in cryostat made of Cu electroformed underground) can achieve a BI of 1 cts/(t·y) in a 4 keV ROI @ $Q_{\beta\beta}$ (i.e. < 10$^{-3}$ cts/(keV·kg·y))
- At the completion of GERDA II and Majorana Demonstrator physics program, Gerda & Majorana projects could merge data & detectors, pinpointing the best technique.
• GERDA I collected 21.6 kg·y exposure in the time period 2011-2013, with
  • BI 10^{-2} cts/(keV · kg · y) and
  • FWHM ~ 4.8 keV (for COAX detectors)
  • FWHM ~ 3.2 keV (for BEGe detectors)
  • Pulse Shape Discrimination with 90% acceptance for efficiency for single site events
• No excess count has been found over the expected background
  After PSD: 3 cts found vs 2.5 expected
  Best fit: N^{0ν} = 0
  N^{0ν} < 3.5 cts @ 90% C.L.
  \( T_{1/2}^{0ν} > 2.1 \times 10^{25} \text{ yr @ 90% CL} \)
• The 0νββ claim has not been confirmed
• Since 2013 GERDA is upgrading to complete Phase II of the foreseen experimental program
  • 21 kg of BEGe detectors w. Enhanced PSD capabilities + 18 kg COAX detectors
  • LAr will be readout and will act as veto
  • FWHM expected <3 keV for BEGe detectors
• The expected sensitivity
  \( T_{1/2}^{0ν} > 1.5 \times 10^{26} \text{ yr @ 90% CL for an exposure of 120 kg·y} \rightarrow m_{ee} < 90 \text{ meV} \)