SEARCHING FOR THE NEUTRINOLESS DOUBLE BETA DECAY WITH GERDA

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on behalf of the GERDA Collaboration
Looking for $^{76}\text{Ge}$ decay with GERDA

GERmanium Detector Array (INFN-LNGS, Italy) searches for 0ν2β decay in $^{76}\text{Ge}$ using HPGe detectors enriched in $^{76}\text{Ge}$

$Q_{\beta\beta}$-value = 2039 keV in $^{76}\text{Ge}$

Energy resolution <4 keV FWHM → important for discovery
GERDA: the Collaboration

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

16 institutions
~110 members
GERDA: the concept

plastic scintillator panels
muon veto

clean room
lock system

590 m$^3$ ultra-pure water
neutron moderator/absorber
muon Cherenkov veto

64 m$^3$ LAr cryostat
coolant, shielding

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GERDA: the concept

- 590 m³ ultra-pure water
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- muon Cherenkov veto
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- clean room
- lock system
- 64 m³ LAr cryostat
- coolant, shielding
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- low activity PMTs
- wavelength shifting fibers with SiPM read-out
- low activity PMTs
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- low activity electronics
- 64 m$^3$ LAr cryostat coolant, shielding
- Ge detector array
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- low activity electronics
- Ge detector array
- low mass detector holder
- 64 m³ LAr cryostat
- coolant, shielding
- low mass, low-activity electronics
- BEGe detector
- plastic scintillator panels
- muon veto
- lock system
- clean room
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- Ge detector array
- low mass detector holder
- 64 m³ LAr cryostat
- coolant, shielding
- low mass, low-activity electronics
- BEGe detector
**Strategy and phases**

**Phase I (Nov 2011- May 2013): Completed**
Use refurbished HdM and IGEX (18 kg) (+ new BEGe Phase II detectors)
B ≈ 0.01 cts / (keV kg yr)
No LAr readout (passive shield)
Accumulated 21 kg yr

**Phase II (Dec 2015- ongoing):**
Add new enrBEGe detectors (20 kg)
BII ≈ 0.001 cts / (keV kg yr)
Goal: 100 kg yr
First data release on Jun 2016 (about 11 kg yr)

**Blind analysis strategy**
Events at $Q_{\beta\beta} \pm 25$ keV in the blinding box
Open box when all cuts finalized

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Phase II Array

- Deployed in **December 2015**
- **40 channels**
  - 30 *enrBEGe* (20 kg)
  - 7 *enrCoax* (16 kg)
  - 3 *natCoax* (8 kg)
Previous Phase II results

- New limit on $^{76}$Ge $T_{1/2}$ (Phase I+II)
  - $T_{1/2} > 5.3 \cdot 10^{25}$ yr @ 90% CL (median sensitivity $4.0 \cdot 10^{25}$ yr)
- Background $< 1$ cts for the full design exposure
  - Coax: $3.5^{+2.1}_{-1.5} \cdot 10^{-3}$ cts/(keV·kg·yr), FWHM: 4.0(2) keV
  - BEGe: $7^{+11}_{-5} \cdot 10^{-4}$ cts/(keV·kg·yr), FWHM: 3.0(2) keV
- $\text{Bck}/\varepsilon = 3.5$ cts/(FWHM ton yr) [BEGe]
DAQ & energy resolution

- **DAQ facts:**
  - 14 bit, 25 MHz continuous running ADC (160 $\mu$s)
  - Leading edge of the pulse sampled at 100 MHz (10 $\mu$s)

- **Energy scale**
  - Offline, using optimized ZAC filter
  - Weekly calibrations with $^{228}$Th sources
  - Stability monitored online with Test Pulses, injected every 20 s

- **Energy resolution**
  - Profile derived from $^{228}$Th calibrations
  - Correction (for coax) applied derived from the resolution of the $^{40}$K and $^{42}$K peaks in the physics data
    - Accounts for instabilities during the long-term data taking

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Coax: 3.90(7) keV
BEGe: 2.93(6) keV

$Q_{\beta\beta}$
Current data taking

- Data taking in progress!
  - Phase II exposure increased by \( x3 \) with respect to Nature paper (Phasella)
  - Valid exposure accumulated 34.4 kg∙yr up to Apr 15\(^{th}\) (Phasellb)
    - 18.2 kg∙yr of BEGe data and 16.2 kg∙yr of enrCoax data
    - A few more kg∙yr already in the bag (Apr-Jul)

June 2017 unblinding

- Box opened for the BEGe dataset only (12.4 kg yr)
- New enrCoax data (11.2 kg yr) still in the box
  - Background comparable (slightly better) to Phase IIa
  - Confident to improve it further by better rejection of \( \alpha \) events from the groove
  - Rejection "\textit{a posteriori}" would spoil the concept of blinding
- Total unblinded exposure: 23.3 kg yr
GERDA spectra

- Most prominent features: $^{39}$Ar $\beta$ (< 500 keV), $2\nu\beta\beta$, $^{42}$K and $^{40}$K $\gamma$-rays, $\alpha$
GERDA spectra

- Most prominent features: $^{39}\text{Ar}\ \beta\ (<500\text{ keV})$, $2\nu\beta\beta$, $^{42}\text{K}$ and $^{40}\text{K}$ γ-rays, α
- PSD clears completely the α region
- LAr and PSD complementary
- Final background at $Q_{\beta\beta}$ $O(10^{-3}\text{ cts/(keV kg yr)})$
  - PSD for coaxials to be further optimized (groove α) → background will decrease
Background modeling

- Very same approach as in Phase I
  - EPJ. C 74 (2014) 2764
  - Mostly, same components considered
  - Also same problem: poor statistics makes difficult to disentangle components
  - Simultaneous fit of multiple data sets and external constraints
  - Screening results used as priors

- Consider the spectrum before LAr and PSD cuts
  - Work in progress to have a full combined fit including LAr, PSD and multi-detector events
  - PDFs being derived by MC

- Established γ-lines from $^{42}\text{K}$, $^{40}\text{K}$, Th chain ($^{228}\text{Ac}$, $^{208}\text{Ti}$), U chain ($^{214}\text{Bi}$ and $^{214}\text{Pb}$), $^{85}\text{Kr}$

- Use the same analysis window as Phase I
  - 1930-2190 keV, excl. ±5 keV around two known γ lines
GERDA Meeting in Cracow (Jun 28\textsuperscript{th}-30\textsuperscript{th})
Spectra in the ROI

7 cts (+2 known in blinded box)

$2.7^{+1.0}_{-0.8} \times 10^{-3}$ cts/(keV kg yr)

**enrCoax**

16.2 kg·yr
(all cuts)

**enrBEGe**

18.2 kg·yr
(all cuts)
Spectra in the ROI

7 cts (+2 known in blinded box)

\[2.7^{+1.0}_{-0.8} \times 10^{-3}\text{ cts/(keV kg yr)}\]

\[\text{enrCoax}\]
\[16.2 \text{ kg}\cdot\text{yr} \]
(all cuts)

Previously unblinded:
\[5.0 \text{ kg yr}\]

\[\text{enrBEGe}\]
\[18.2 \text{ kg}\cdot\text{yr} \]
(all cuts)

\[2 \text{ cts} + 2 \text{ new} > 10\sigma \text{ from } Q_{\beta\beta}\]

\[1.0^{+0.6}_{-0.4} \times 10^{-3}\text{ cts/(keV kg yr)}\]
Statistical analysis

- Combined unbinned **maximum likelihood fit** of the six spectra
  - **Frequentist:** test statistics and method after Cowan et al., EPJC 71 (2011) 1554
  - **Bayesian:** flat prior on $1/T_{1/2}$ between 0 and $10^{-24}$ yr$^{-1}$
  - Systematic uncertainties folded as pull terms or by Monte Carlo

<table>
<thead>
<tr>
<th>Exposure (kg·yr)</th>
<th>Phase I (4 sets)</th>
<th>Phase II – coax</th>
<th>Phase II – BeGe</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.5</td>
<td>5.0</td>
<td>5.8 + 12.4 = 18.2</td>
<td></td>
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</tbody>
</table>

\[ 46.7 \text{ kg} \cdot \text{yr} \]

\[ T_{1/2} > 8.0 \cdot 10^{25} \text{ yr @ 90\% CL} \]

It was $5.3 \cdot 10^{25}$ yr in Phasella

MC Median sensitivity (no signal): $5.8 \cdot 10^{25}$ yr (for 90\% C.L.)

30\% chance to have a better limit

\[ T_{1/2} > 5.1 \cdot 10^{25} \text{ yr @ 90\% CI} \]

Median sensitivity $4.5 \cdot 10^{25}$ yr
Next steps

- **Phase I** (23.5 kg yr)
  - Sensitivity: $2.4 \cdot 10^{25}$ yr
  - Limit: $T_{1/2}^{0v} > 2.1 \cdot 10^{25}$ yr (90%CL)
- **Phase IIa** (PhI + 10.8 kg yr)
  - Sensitivity: $4.0 \cdot 10^{25}$ yr
  - Limit: $T_{1/2}^{0v} > 5.3 \cdot 10^{25}$ yr (90%CL)
- **This release** (PhIIa + 12.4 kg yr)
  - Sensitivity: $5.8 \cdot 10^{25}$ yr
  - Limit: $T_{1/2}^{0v} > 8.0 \cdot 10^{25}$ yr (90%CL)
- Already in the bag:
  - 11.2 kg yr of **validated** enrCoax data
    - Median sensitivity → $7.1 \cdot 10^{25}$ yr
    - ~ 4 kg yr taken after Apr 15th
- **Break** $10^{26}$ yr wall (sensitivity) in mid-2018
- Design exposure 100 kg yr
  - Background-free
  - Final sensitivity $1.3 \cdot 10^{26}$ yr (for limit) or ~ $8 \cdot 10^{25}$ yr (50% for $3\sigma$ discovery)
Conclusions

• GERDA Phase II taking data since 1.5 years
  • Valid exposure of 34 kg·yr accumulated (analysis cutoff: Apr 15th)
  • A few more kg yr available in the recent runs
• Very good background level at Q$_{\beta\beta}$ confirmed
  • $2.7^{+1.0}_{-0.8}$ (enrCoax) and $1.0^{+0.6}_{-0.4}$ (enrBEGe) [10$^{-3}$ cts/(keV kg yr)]
  • Will allow to achieve O(< 1 count) in the ROI for the full design exposure
• Lowest background (~10x) in ROI wrt other isotopes
• Unblinding of 12.4 kg·yr of best-quality data
  • $T_{1/2} > 8.0 \cdot 10^{25}$ yr @ 90% CL ($m_{\beta\beta} < 0.12$-$0.27$ eV)
  • Median sensitivity: $5.8 \cdot 10^{25}$ yr (~ KamLAND-Zen 2016)
  • 11.2 kg yr of valid enrCoax data still blinded
• For full 100 kg·yr exposure: sensitivity to a signal up to $T_{1/2} \sim 8 \cdot 10^{25}$ yr (or limit $T_{1/2} > 1.3 \cdot 10^{26}$ yr at 90%CL )