Search for the neutrino-less double beta decay with the GERDA experiment

Status of Phase II

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0νββ decay

\[ (A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e \]

allowed and observed

\[ (T_{1/2}^{0\nu})^{-1} = F^{0\nu} \cdot |\mathcal{M}^{0\nu}|^2 \cdot \langle m_{\beta\beta} \rangle^2 \]

\[ \langle m_{\beta\beta} \rangle^2 = |\sum_i U_{ei}^2 m_{\nu i}|^2 \]

- nuclear matrix element
- phase space integral depends on the Q value
- effective neutrino mass

2β decay with 2 neutrinos

2β decay with 0 neutrinos

(A,Z) → (A,Z+2) + 2e^-

violates lepton number conservation
0νββ in $^{76}$Ge

- HPGe detector made of enriched $^{76}$Ge - source and detector are the same
- Ge detector good resolution ~0.1 % FWHM:
  - Good signal to noise ratio, small ROI
  - in-situ background recognition
- Was used to get the best results achieved so far

- IGEX no signal $T_{1/2} > 1.6 \times 10^{25}$ yr
- HdM no signal $T_{1/2} \geq 1.9 \times 10^{25}$ yr
- Klapdor-Kleingrothaus et alii claim of evidence: $T_{1/2} = 1.9 \times 10^{25}$ yr
GERDA status

- **Goal of Phase I**: Re-deploy HdM and IGEX detectors (18 kg) in LAr with a background of 0.01 cts/(keV kg yr), scrutinize the claim.

- **Status of Phase I**: data taking ended with 21.6 kg · yr exposure: from Nov. 2011 to May 2013.

- **Goal of Phase II**: background level of 0.001 cts/(keV kg yr) and 100 kg yr exposure.

- **Status of Phase II**: under construction: 30 new HPGe detectors (~20 kg) are ready to be deployed.
GERDA at Gran Sasso

INFN - LNGS underground lab. 3800 m w.e. overburden

Home of many Dark Matter and Double Beta Decay experiments

GERDA infrastructure:

- 590 m$^3$ water tank,
- 64 m$^3$ LAr cryostat
GERDA Phase I

- HdM and IGEX detectors refurbished
- operated bare in LAr
- 8 coax detectors with 18 kg mass
- 5 BEGe detectors (3 kg) added in June 2012
- Total exposure of 21.6 kg yr between Nov. 2011 and May 2013
Background

- Dominated by $^{214}$Bi and $^{228}$Th nearby sources (det. holders etc.) and surface contaminations - $^{42}$K and alphas
- Contribution of remote sources is negligible
- The strongest gamma line is 1525 keV from $^{42}$K
- Flat background around 2 MeV
In 2039 ±5 keV we see 7 counts, after PSD only 3 remain:

\[ T^{0\nu}_{1/2} > 2.1 \times 10^{25} \text{ yr} \]
(90% C.L.)


From H.V. Klapdor-Kleingrothaus et al. / *Physics Letters B* 586 (2004) we expect to see 6 signal events.

data set  \( \mathcal{E}[\text{kg} \cdot \text{yr}] \)  \( \langle \epsilon \rangle \)  bkg  BI †)  cts

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<tr>
<td>without PSD</td>
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<tr>
<td>golden</td>
<td>17.9</td>
<td>0.688 ± 0.031</td>
<td>76</td>
<td>18±2</td>
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<tr>
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<tr>
<td>golden</td>
<td>17.9</td>
<td>0.619^{+0.044}_{-0.070}</td>
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<td>BEGe</td>
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<td>0.663 ± 0.022</td>
<td>3</td>
<td>5^{+4}_{-3}</td>
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†) in units of \( 10^{-3} \text{ cts/(keV·kg·yr)} \).
Combined results

- All $^{76}$Ge experiments combined give: $T_{1/2} > 3.0 \times 10^{25}$ yr
- The claim is disfavoured also by the $^{136}$Xe experiments

$\textbf{H1}$: signal with $T_{1/2}^{0\nu} = 1.19 \times 10^{25}$ yr
$\textbf{H0}$: background only

<table>
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<tr>
<th>Isotope</th>
<th>$P(H_1)/P(H_0)$</th>
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<tbody>
<tr>
<td>GERDA</td>
<td>$^{76}$Ge</td>
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<tr>
<td>GERDA+HdM+IGEX</td>
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<td>KamLAND-Zen*</td>
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<td>EXO-200*</td>
<td>$^{136}$Xe</td>
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<td>GERDA+KLZ+EXO*</td>
<td>$^{76}$Ge + $^{136}$Xe</td>
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</tbody>
</table>

Matrix elements from:

Phase II Upgrade

\[ T_{1/2}^{0\nu} \approx \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \text{ [yr]} \]

- **More mass:** From the available 37.5 kg enriched germanium 30 new detectors were produced (~20 kg)
  - 5 of the new BEGe detectors already deployed in Phase I.

- **Lower background:** the goal is 10x lower background
  - New detector holders and new FE electronics
  - ‘BEGe’ detectors for better Pulse Shape Analysis
  - New lock was built to accommodate the LAr veto with PMTs and WLS fibers
Detector Production

- Whole production chain from $^{\text{enr}}\text{GeO}_2$ to BEGe diode organized by GERDA and tested with $^{\text{dep}}\text{Ge}$ (JINST 8 P04018 2013)

- Total gain 30 BEGes with 20.5 kg (58 % yield)

- Detector characterization in HADES underground facility, Belgium

- Exposure to cosmic rays reduced as much as possible:
  - Transport in shielded container
  - Storage and testing underground
Broad Energy Ge detectors

- BEGe detectors for improved PSD capabilities
  - Single Site Event (SSE) = signal like event
  - Multi- Site Event = background: smaller A/E ratio
  - Powerful surface event rejection
  - 92% signal acceptance with 80% background rejection (Phase I)
Detector holders

- New holder made of silicon plates
  - Silicon is cleaner
  - 3x less copper than in the Phase I holder
- Front-End integrated in the flat signal cable
- FE wire bonded to the detector
- One string (off 7) already in GERDA
LAr - veto

**HPGe detector array**

Copper “shroud” with Tetratex reflector coated with TPB

SiPMs

Fiber “shroud” ~800 m WLS fiber coated with TPB

3” low-background PMT
Hamamatsu R11065-20

Detection of LAr scintillation light

Design:
- low-background photo-multipliers (9 top, 7 bottom)
- wave-length-shifting fibers read-out by SiPMs
- wave-length-shifting nylon mini-shroud

Matteo Agostini (TU Munich)
LAr - veto, PMTs

- 16x 3-inch PMTs are operated in the GERDA cryostat w/ liquid argon to detect 128 nm scintillation light
- photocathodes are coated with wavelength shifter (TPB+PST)
- use of custom made encapsulated low-background voltage dividers
Fibers & SiPMs

- **SiPM - Self made packaging from radio-pure materials (Cuflon)**

- **3x3 mm$^2$, 50 μm and 100 μm pixel SiPMs**

- **90 SiPMs to 15 read-out channels**

- **Total SiPM sensitive surface 8.1 cm$^2$**

- **Total fiber surface 3.2 m$^2$**
LAr veto commissioning

- Presently: commissioning runs with LAr-veto turned on
- Combining PSD and LAr veto a suppression factor of 340 in the ROI is achieved.
- In total (AC+LAr+PSD) gives a SF of ~400 of the Th-228 spectrum.
Summary

- The Phase I of GERDA was ended after 21.6 kg yr exposure.
- Background goal of 0.01 cts/(keV kg yr) was achieved
- No indication of $0\nu\beta\beta$ signal $\Rightarrow T_{1/2} > 2.1 \times 10^{25}$ yr
- Phase II commissioning started, 30 new detectors are ready to be deployed