Search for Neutrinoless Double Beta Decay of $^{76}$Ge in the GERDA Experiment

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— on behalf of the Gerda Collaboration —

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Lake Louise Winter Institute

20$^{\text{st}}$ February 2015
Motivation for $0\nu\beta\beta$-search

GERDA experiment

Results from Phase I

Towards Phase II
Unveiling the nature of the neutrino...

- absolute mass scale?
- mass hierarchy (normal or inverted)?
- physics beyond SM (e.g. lepton number violation, see-saw mechanism, ...)?

... and ...
Unveiling the nature of the neutrino...

Dirac: $\nu \neq \bar{\nu}$

Majorana: $\nu = \bar{\nu}$

VS.

... by Double Beta ($\beta\beta$) decay

rare second order nuclear transition occurs between 2 even-even isobars

single $\beta$ decay energetically forbidden or $\Delta J$ large

35 isotopes in nature

$\beta\beta$ emitters used in experiments

$48$ Ca Candles

$76$ Ge Gerda, Majorana

$82$ Se Nemo

$100$ Mo Cobra

$116$ Cd

$130$ Te Cuore

$136$ Xe Exo, KamLand-Zen

$150$ Nd Sno+

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Search for $0\nu\beta\beta$ in GERDA
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Double Beta ($\beta\beta$) decay

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

- allowed by Standard Model
- $\Delta L = 0$
- so far observed in up to 12 nuclei with half lifes $\sim (10^{18} - 10^{24})$ yr
  $T_{1/2}^{2\nu}(^{76}\text{Ge}) = 1.84^{+0.14}_{-0.10} \cdot 10^{21}$ yr

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

- prohibited by Standard Model
- $\Delta L = 2$
- only if $\nu$ has Majorana mass component
- still hunted process; mediated by e.g. light Majorana $\nu$, R-handed weak currents, SUSY particles, ...

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Experimental signatures
- measure the electrons
- sum energy spectrum
- continuum $\rightarrow 2\nu\beta\beta$
- or $0\nu\beta\beta +$ Majoron(s)
- monoenergetic peak at $Q_{\beta\beta}$-value $\rightarrow 0\nu\beta\beta$

$Q_{\beta\beta} = E_{e1} + E_{e2} - 2m_e$
- for $^{76}\text{Ge}$
- $(2039.061 \pm 0.007)$ keV
  
Neutrinoless Double Beta ($0\nu\beta\beta$) decay

Decay rate (if light Majorana $\nu$ exchange is dominating process)

\[
(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)|M^{0\nu}|^2 \langle m_{\beta\beta} \rangle^2
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- $G^{0\nu}(Q_{\beta\beta}, Z) \propto Q_{\beta\beta}^5 = \text{phase space integral}$
- $|M^{0\nu}| = \text{nuclear matrix element}$
- $\langle m_{\beta\beta} \rangle = |\sum_{i=1}^{3} U_{ei} m_i| = \text{effective } \nu \text{ mass}$

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1. Background \(\ll 1\): 
   
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   T_{1/2}^{0\nu} \propto \epsilon \cdot a \cdot M \cdot t
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2. Background \(\gg 1\): 
   
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   T_{1/2}^{0\nu} \propto \epsilon \cdot a \cdot \sqrt{\frac{M \cdot t}{B I \cdot \Delta E}}
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- $\epsilon = $ total detection efficiency
- $a = $ abundance of $0\nu\beta\beta$ isotope
- $M \cdot t = $ exposure (detector mass $\times$ livetime)
- $B I = $ background index
- $\Delta E = $ energy resolution @ $Q_{\beta\beta}$
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- $M \cdot t = $ exposure (detector mass $\times$ livetime)
- $BI = $ background index
- $\Delta E = $ energy resolution @ $Q_{\beta\beta}$

## Search in $^{76}$Ge (using well established semiconductor technology)

### Advantages
- source = detector $\rightarrow$ high $\epsilon$
- High Purity Ge $\rightarrow$ low intrinsic $BI$
- FWHM @ $Q_{\beta\beta}$ $\sim 0.2\%$ $\rightarrow$ excellent $\Delta E$
- test of $0\nu\beta\beta$ observation by parts of Hdm without depending on NME

### Disadvantages
- low $Q_{\beta\beta}$-value $\rightarrow$ possible external $BI$ from e.g. $^{208}$Tl + small $G^{0\nu}(Q_{\beta\beta}, Z)$
- $a=7.8\%$ for $^{76}$Ge $\rightarrow$ enrichment needed
- rather long and costly process to get large active detector mass

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Search for $0\nu\beta\beta$ in GERDA  
20\textsuperscript{st} February 2015 5 / 19
located @ LNGS underground laboratory, Italy (3400 m w.e. → cosmic $\mu$ flux reduced by $10^6$)

surrounding rock shielded by tank with ultra-pure water, the copper lined cryostat and LAr

plastic scintillators above cryostat neck and water instrumented with PMTs as active $\mu$-veto

detectors are operated bare in LAr as coolant
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minimal amount of (screened) material close to the detectors

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<th>$^{40}$K [(\mu\text{Bq})]</th>
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GERDA Timetable

Experiment proceeds in two phases:

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**Semi-coaxial**

- inherited from HdM (ANG1-5) and Igex (RG1-3) experiments; all reprocessed at Canberra
- enrichment fraction of $^{76}\text{Ge} \sim 86\%$

**Broad Energy Germanium (BEGe)**

- $\sim 30$ newly processed detectors
- enrichment fraction of $^{76}\text{Ge} \sim 88\%$
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- Enrichment fraction of $^{76}$Ge $\sim$88%

**Phase I data taking**

- Nov 2011 - May 2013: 8x detectors not considered due to high leakage current
- Total mass = 14.6 kg
- July 2012 - May 2013: 5x detectors not considered due to unstable behaviour
- Total mass = 3.0 kg
Physics spectrum

- $\beta$-spectrum of $^{39}$Ar (with $Q = 565$ keV)
- $2\nu\beta\beta$-spectrum of $^{76}$Ge
- $\gamma$-lines of $^{40}$K, $^{42}$K, $^{60}$Co, $^{214}$Bi, $^{212}$Bi and $^{208}$Tl
- $\alpha$-spectrum of $^{238}$U chain (in semi-coaxial detectors)

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region of interest (ROI) = interval $[1930 - 2190]$ keV
blinded window @ $Q_{\beta\beta} \pm 20$ keV to not bias analysis
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Blinded window @ $Q_{\beta\beta} \pm 20$ keV to not bias analysis

Division into 3 sub-sets:
- Semi-coaxial data splitted in "golden" / "silver" due to $BI$
- "BEGe" kept separated because of better $E$ resolution

General procedure

- simulation of known (material screening) and observed background sources
- spectral fit with combination of all components in [570 - 750] keV on the 3 data-sets
- 2 extremes: "minimum" (all known + visible contributions) & "maximum" (additional contributions from other possible locations)

![Graph showing background model](image-url)
Background model  


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Results

- no $\gamma$-line expected around $Q_{\beta\beta}$
- flat background for ROI excluding known peaks @ $2103$ keV ($^{208}$Tl), $2119$ keV ($^{214}$Bi)

**BI**

- $1.75 \pm 0.26 \times 10^{2}$ cts kg$^{-1}$ keV$^{-1}$ yr

**BEGe**

- $3.6 \pm 1.3 \times 10^{2}$ cts kg$^{-1}$ keV$^{-1}$ yr

**GERDA 13-03**

**GOLD-coax**

- Alphas
- $^{214}$H
- $^{214}$P
- $^{42}$K
- $^{40}$K
- $^{60}$Co
- $^{228}$Ac
- $^{228}$Th

- data/model ratio
  - 68%
  - 95%
  - 99.9%

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20st February 2015
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- no $\gamma$-line expected around $Q_{\beta\beta}$
- flat background for ROI excluding known peaks @ $2103$ keV ($^{208}$Tl), $2119$ keV ($^{214}$Bi)
  - " golden": $BI_{1} = 1.75 \pm 0.26 \pm 0.24 \times 10^{-2}$ cts kg$^{-1}$ keV$^{-1}$ yr$^{-1}$
  - " BEGe": $BI_{1} = 3.6 \pm 1.3 \pm 1.0 \times 10^{-4}$ cts kg$^{-1}$ keV$^{-1}$ yr$^{-1}$

General procedure

- simulation of known (material screening) and observed background sources
- spectral fit with combination of all components in $[570 - 7500]$ keV on the 3 data-sets
- 2 extremes: "minimum" (all known + visible contributions) & "maximum" (additional contributions from other possible locations)

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- flat background for ROI excluding known peaks @ 2103 keV ($^{208}$Tl), 2119 keV ($^{214}$Bi)
- "golden": $BI = 1.75^{+0.26}_{-0.24} \cdot 10^{-2}$ cts $\frac{kg \cdot keV \cdot yr}{\frac{ct}{keV \cdot yr}}$
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Partial unblinding @ \(Q_{\beta\beta} \pm 20\) keV \(\rightarrow \pm 5\) keV with \(8.6 / 10.3\) expected and 13 observed events
Background reduction by off-line analysis

**Signal**
- $\beta\beta$ events; range of $\sim 1\text{MeV}$ electron in Ge @ 1mm
- interaction via ionization or exitation of absorber atoms
- drift of electrons and holes originated close-by in a single located charge cloud
- $\rightarrow$ single-site event (SSE)

**Background**
- $\gamma$ events; range of $\sim 1\text{MeV}$ gammas in Ge about $10 \times$ larger (compared to electrons)
- interaction via compton scattering, $e^+e^-$ pair creation or photoelectric absorption
- sum of several separated electron-hole drifts
- $\rightarrow$ multi-site event (MSE)

**Event processing**
(diode $\rightarrow$ amplifier $\rightarrow$ FADC $\rightarrow$ digital filter $\rightarrow$ $E$/PSD/etc...)

- quality cuts; $E$ monitored by weekly calibration with movable $^{228}\text{Th}$ source: $\sim 9\%$ rejected @ $Q_{\beta\beta}$
- anti-coincidence muon/2nd Ge-diode: $\sim 20\%$ rejected @ $Q_{\beta\beta}$
- PSD based on location(s) of energy deposition inside the active volume: $\sim 50\%$ rejected @ $Q_{\beta\beta}$
Pulse shape: BEGe

Ramo-Shockley theorem

- Charge $Q(t)$
  
  $$Q(t) = -q \times \left[ \phi(r_h(t)) - \phi(r_e(t)) \right]$$

- Current $I(t) = dQ(t)/dt$
  
  $$I(t) = q \times \left[ \mathbf{E}(r_h(t)) \cdot \mathbf{v}_h(t) - \mathbf{E}(r_e(t)) \cdot \mathbf{v}_e(t) \right]$$

→ mostly holes (but hardly any electrons) do contribute to the signal formation!
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Signal-like single-site event (SSE)

\[ A \propto E \]

Background-like multi-site event (MSE)

\[ A \propto E \]
PSD parameter $A/E$

$A = \text{amplitude of current pulse}$

$E = \text{energy}$

- high capability of distinguishing SSE from MSE and surface $p^+$ or $n^+$ events
- tuned using double escape peak (DEP) of $^{208}\text{Tl}$ (where per definition $A/E=1$), compton continuum and $2\nu\beta\beta$ events
- keep events with $0.965 < A/E < 1.07$
- $0\nu\beta\beta$-signal acceptance $= (92 \pm 2)\%$
- background acceptance $\leq 20\%$
- well tested and documented method!

JINST 4 (2009) P10007
JINST 6 (2011) P03005
...

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Pulse shape: semi-coaxial vs. BEGe

simulated current pulses for SSEs

→ only holes, no electrons

→ both, holes & electrons

Different PSD method than mono-parametric $A/E$ needed for semi-coaxial detector type!
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Different PSD method than mono-parametric

\[ \frac{A}{E} \] needed for semi-coaxial detector type!
PSD method ANN  

ANN = artificial neural network

- input variables: time when charge pulse reaches 1%, 3%, ..., 90% of maximum amplitude ($n_{\text{var}}=50$)
- TMVA (TMlpANN algorithm) with 2 hidden layers of $n_{\text{var}}$ and $n_{\text{var}}+1$ nodes
- training using $^{228}\text{Th}$ calibration data
  - SSE: $^{208}\text{Tl}$ DEP @ 1620.7 keV
  - MSE: $^{212}\text{Bi}$ FEP @ 1592.5 keV
- cut defined such that the acceptance of $^{208}\text{Tl}$ DEP is fixed to 90%
- $0\nu\beta\beta$-signal acceptance = $(90 \pm \frac{5}{9})\%$
  - background acceptance @ $Q_{\beta\beta} \sim 55\%$
- further cross checked by:
  - $2\nu\beta\beta$-event acceptance = $(85 \pm 2)\%$
  - SSE part of compton edge = $(85 - 94)\%$
  - $^{60}\text{Co}$ calibration DEPs = $(83 - 95)\%$
  - two other independent PSD methods
Unblinding @ $Q_{\beta\beta} \pm 5$ keV


\[ T_{1/2}^{0\nu} = \frac{\ln(2) \cdot N_A}{m_A \cdot N_{0\nu}} \cdot M \cdot t \cdot f_{76} \cdot f_{av} \cdot \varepsilon_{\text{fep}} \cdot \varepsilon_{\text{psd}} \]

\begin{align*}
\text{data set} & \quad \text{PSD} & \quad \text{Exposure} & \quad \text{FWHM @} & \quad a \cdot \epsilon \\
\text{golden} & \quad \text{w/o} & \quad 17.9 & \quad 4.8 \pm 0.2 & \quad 0.688 \\
\text{w/} & & & & \quad 0.619 \\
\text{silver} & \quad \text{w/o} & \quad 1.3 & \quad 4.8 \pm 0.2 & \quad 0.688 \\
\text{w/} & & & & \quad 0.619 \\
\text{BEGe} & \quad \text{w/o} & \quad 2.4 & \quad 3.2 \pm 0.2 & \quad 0.720 \\
\text{w/} & & & & \quad 0.663
\end{align*}
Unblinding @ $Q_{\beta\beta} \pm 5$ keV

\[ T_{1/2}^{0\nu} = \frac{\ln(2) \cdot N_A}{m_A \cdot N_0^{0\nu}} \cdot M \cdot t \cdot \overline{f_{76}} \cdot f_{av} \cdot \epsilon_{\text{fep}} \cdot \epsilon_{\text{psd}} \cdot \text{efficiency} \cdot \epsilon \]

<table>
<thead>
<tr>
<th>data set</th>
<th>PSD</th>
<th>Exposure [kg yr]</th>
<th>FWHM @ $Q_{\beta\beta}$ [keV]</th>
<th>$a \cdot \epsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>golden</td>
<td>w/o</td>
<td>17.9</td>
<td>4.8±0.2</td>
<td>0.688</td>
</tr>
<tr>
<td></td>
<td>w/</td>
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<td></td>
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<td></td>
<td></td>
<td>0.663</td>
</tr>
</tbody>
</table>

Events @ ROI

<table>
<thead>
<tr>
<th>Events @ ROI</th>
<th>$N_{\text{exp}}$</th>
<th>$N_{\text{obs}}$</th>
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<tr>
<td></td>
<td>76</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>45</td>
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<td></td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

\( \rightarrow \) GERDA sets limit on $0\nu\beta\beta$ half-life

no peak observed @ $Q_{\beta\beta}$
frequentist approach: profile likelihood fit in $[1930-2190]$ keV interval with 4 free parameters:
3× constant bkgd (different data sets)
1× gauss with common $T_{1/2}^{0\nu} > 0$
(systematic uncertainties on $a$, $\epsilon$, $\mu$, $\sigma$)
  → best fit $N^{0\nu}=0$
  → $T_{1/2}^{0\nu}(90\%C.L.) > 2.1 \cdot 10^{25}$ yr
  → median sensitivity: $2.4 \cdot 10^{25}$ yr

Bayesian approach:
flat prior for $1/T_{1/2}^{0\nu}$ in $[0; 10^{-24}]$ yr$^{-1}$
  → best fit $N^{0\nu}=0$
  → $T_{1/2}^{0\nu}(90\%C.L.) > 1.9 \cdot 10^{25}$ yr
  → median sensitivity: $2.0 \cdot 10^{25}$ yr

<table>
<thead>
<tr>
<th>data set</th>
<th>PSD</th>
<th>Exposure [kg·yr]</th>
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</tr>
<tr>
<td></td>
<td>w/</td>
<td></td>
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</tbody>
</table>
Comparison with other $0\nu\beta\beta$ experiments

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Experiment</th>
<th>$T^{0\nu}_{1/2}$ (90% C.L.) $[10^{25}\text{yr}]$</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{76}\text{Ge}$</td>
<td>HdM</td>
<td>$&gt; 1.9$</td>
<td>[1]</td>
</tr>
<tr>
<td></td>
<td>IGEX</td>
<td>$&gt; 1.6$</td>
<td>[2]</td>
</tr>
<tr>
<td></td>
<td>parts of HdM</td>
<td>$= 1.19^{+0.37}_{-0.23}$</td>
<td>[3]</td>
</tr>
<tr>
<td></td>
<td>GERDA</td>
<td>$&gt; 2.1$</td>
<td>[4]</td>
</tr>
<tr>
<td>$^{136}\text{Xe}$</td>
<td>EXO</td>
<td>$&gt; 1.1$</td>
<td>[5]</td>
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<tr>
<td></td>
<td>KamLAND-Zen</td>
<td>$&gt; 1.9$</td>
<td>[6]</td>
</tr>
<tr>
<td>$^{130}\text{Te}$</td>
<td>CUORICINO</td>
<td>$&gt; 0.28$</td>
<td>[7]</td>
</tr>
<tr>
<td>$^{100}\text{Mo}$</td>
<td>NEMO-3</td>
<td>$&gt; 1.1$</td>
<td>[8]</td>
</tr>
</tbody>
</table>

**H0:** bkgd compatible with GERDA result; only $2.0 \pm 0.3$ bkgd cts in $Q_{\beta\beta} \pm 2\sigma_E$

**H1:** GERDA sees signal from claim in Ref. [3]; add $5.9 \pm 1.4$ signal cts in $Q_{\beta\beta} \pm 2\sigma_E$

→ profile likelihood: $p(N^{0\nu}=0|H1)=0.01$

→ Bayes factor: $p(H1)/p(H0)=0.024$

→ search for $0\nu\beta\beta$-signal "open" again!

---

On the way to GERDA Phase II

Different strategies in parallel needed to push sensitivity

- **Phase I:** 20 kg·yr with $BI$ of $\sim 10^{-2}$ cts/(kg·keV·yr)
- **Phase II:** 100 kg·yr with $BI$ of $\sim 10^{-3}$ cts/(kg·keV·yr)
On the way to GERDA Phase II

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- Phase I: 20 kg·yr with $BI$ of $\sim 10^{-2}$ cts/(kg·keV·yr)
- Phase II: 100 kg·yr with $BI$ of $\sim 10^{-3}$ cts/(kg·keV·yr)

1. avoid close-by background sources:
   - use cleaner signal and HV cables
   - reduce material for holders
   - special care in crystal production

expected Phase II sensitivity $>10^{-26}$ yr (90\% C.L.); factor 7 better than Phase I

first data from pilot string taken these days!
On the way to GERDA Phase II

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   - special care in crystal production

2. **increase mass:**
   - 30 additional BEGe detectors ($\sim 20$ kg)
On the way to **GERDA Phase II**

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3. **reject residual background radiation by:**
   - optimized Pulse Shape Analysis
   - LAr scintillation light veto

9×3” PMT

Cu-shroud & wavelength shifter

fibres with SiPM read-out

Cu-shroud & wavelength shifter

7×3” PMT
On the way to GERDA Phase II

Different strategies in parallel needed to push sensitivity

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- **Phase II:** 100 kg·yr with $BI$ of $\sim 10^{-3}$ cts/(kg·keV·yr)

1. avoid close-by background sources:
   - use cleaner signal and HV cables
   - reduce material for holders
   - special care in crystal production

2. increase mass:
   - 30 additional BEGe detectors (~20 kg)

3. reject residual background radiation by:
   - optimized Pulse Shape Analysis
   - LAr scintillation light veto

Expected Phase II sensitivity

$\sim 1.4 \times 10^{-26}$ yr ($90\%$ C.L.);

factor 7 better than Phase I

First data from pilot string taken these days!
On the way to GERDA Phase II

Different strategies in parallel needed to push sensitivity

- **Phase I**: 20 kg yr with $BI$ of $\sim 10^{-2}$ cts/(kg·keV·yr)
- **Phase II**: 100 kg yr with $BI$ of $\sim 10^{-3}$ cts/(kg·keV·yr)

1. **Avoid close-by background sources**:
   - use cleaner signal and HV cables
   - reduce material for holders
   - special care in crystal production

2. **Increase mass**:
   - 30 additional BEGe detectors ($\sim 20$ kg)

3. **Reject residual background radiation by**:
   - optimized Pulse Shape Analysis
   - LAr scintillation light veto

- **Expected Phase II sensitivity** $\approx 1.4 \cdot 10^{26}$ yr (90% C.L.); factor 7 better than Phase I

- **First data from pilot string taken these days!**
Conclusion: Phase I (2011 – 2013)

- data taking completed with an exposure of 21.6 kg·yr
- blind analysis performed (for the first time in this field)
- unprecedented $BI$ of $\sim 10^{-2}$ cts/(kg·keV·yr) after PSD (order of magnitude lower than previous experiments)
- upper half-life limit from profile likelihood fit:

$$T_{1/2}^{0\nu}(90\%C.L.) > 2.1 \cdot 10^{25} \text{ yr} \text{ with GERDA alone}$$

$\rightarrow$ HdM claim (2004) rejected @ 99% level

$$T_{1/2}^{0\nu}(90\%C.L.) > 3.0 \cdot 10^{25} \text{ yr} \text{ with GERDA+HdM[1]+IGEX[2]}$$

$\rightarrow$ for light Majorana $\nu$ exchange: $\langle m_{\beta\beta} \rangle = (0.2–0.4) \text{ eV}$


Outlook: Phase II (upcoming)

- new BEGe detectors of additional $\sim 20$ kg $\rightarrow$ available
- upgrade of infrastructure (lock system, glove box, ...) $\rightarrow$ finished
- liquid argon scintillation veto $\rightarrow$ installed
- last integration tests (new contacting, electronics, ...) $\rightarrow$ ongoing
The Collaboration

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

Andrea Kirsch (MPIK)
The Collaboration

... and the people behind the experiment.

Picture taken during last GERDA Meeting in June 2014 hosted by the Max-Planck-Institut für Kernphysik @ Heidelberg, Germany
Search for $0\nu\beta\beta$ in GERDA
Gerda in fast motion

Andrea Kirsch (MPIK)
Search for $0\nu\beta\beta$ in GERDA

20st February 2015
Calibration, time stability and energy resolution

- (bi-) weekly calibration with movable $^{228}\text{Th}$ sources
- offline energy reconstruction (semi-Gaussian filter)
- also to check resolution and gain stability over time

short term drifts monitored with test pulser (0.05 Hz)
Calibration, time stability and energy resolution

- shift of $^{208}$Tl FEP position @ 2614.5 keV relative to previous calibration

- drifts small compared to FWHM @ $Q_{\beta\beta}$ $\sim$0.2%
- peak within 0.3 keV at correct position (from $^{42}$K peak)
Calibration, time stability and energy resolution

- Energy resolution $@ Q_{\beta\beta}$

- FWHM from physics runs $\sim 4\%$ larger than expected from calibration data

- Exposure weighted FWHM $@ Q_{\beta\beta}$ is:
  1. $(4.8 \pm 0.2)$ keV for semi-coaxial
  2. $(3.2 \pm 0.2)$ keV for BEGe
Overview of data taking and publications

**duty cycle**

- (bi-) weekly calibration with $^{228}$Th source → spikes
- in between: Phase I physics measurements

- Run 25-32
- Exposure of 5.04 kg·yr
- Run 25-43
- Exposure of 18.5 kg·yr
- 15.4 kg·yr for “golden”
- 1.3 kg·yr for “silver”
- 1.8 kg·yr for “BEGe”

- Run 25-46
- Exposure of 21.6 kg·yr
- 17.2 kg·yr for “golden”
- 2.4 kg·yr for “BEGe”

- Run 1-24 for commissioning
- Run 33 not considered
- flat parts: BEGE insertion & maintenance
- total livetime = 492.3 days

Andrea Kirsch (MPIK)
Search for $0\nu\beta\beta$ in GERDA
20th February 2015
25 / 19
Overview of data taking and publications

**2νββ analysis**
- Run 25-32 = exposure of 5.04 kg·yr
  

**background model**
- Run 25-43 = exposure of 18.5 kg·yr
  - 15.4 kg·yr for “golden”
  - 1.3 kg·yr for “silver”
  - 1.8 kg·yr for “BEGe”


**0νββ analysis**
- Run 25-46 = exposure of 21.6 kg·yr
  - 17.2 kg·yr for “golden”
  - 1.3 kg·yr for “silver”
  - 2.4 kg·yr for “BEGe”


**0νββχ analysis**
- Run 25-46 = exposure of 20.3 kg·yr
  - 17.2 kg·yr for “golden”
  - 2.4 kg·yr for “BEGe”


**duty cycle**
- (bi-) weekly calibration with $^{228}$Th source → spikes
- in between: Phase I physics measurements

---

Run 1 – 24 for commissioning
Run 33 not considered
flat parts: BEGE insertion & maintenance
total livetime = 492.3 days
$T^{2\nu}_{1/2}$ measurement of $^{76}$Ge


- data sub-set: first 5.04 kg·yr were used to evaluate the half-life of the $2\nu\beta\beta$ decay
- fit window: (600–1800) keV
- binned maximum likelihood approach
- model contains MC spectra of $2\nu\beta\beta$, $^{42}$K, $^{40}$K, $^{214}$Bi

$2\nu\beta\beta$ half-life important for understanding of $0\nu\beta\beta$ (e.g. nuclear matrix element)

Final result:

$T^{2\nu}_{1/2} = 1.84^{+0.14}_{-0.10} \cdot 10^{21}$ yr
Background model: “coax” vs. “BEGe”

Andrea Kirsch (MPIK)

Search for $0\nu\beta\beta$ in GERDA

20\textsuperscript{st} February 2015
Background model: “minimum” vs. “maximum” @ $Q_{\beta\beta}$