Phase II status

József Janicskó Csáthy for the GERDA collaboration
GERDA

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

16 institutions
~100 members
Double-beta decay

\[ \beta\beta \text{ decay with 2 neutrinos} \quad (A,Z) \rightarrow (A,Z+2) + 2e^- + 2\nu e \]
allowed and observed

- If 0\(\nu\)2\(\beta\) decay is observed neutrinos have a Majorana mass component
- The measured half life converts in neutrino mass

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

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

\[ M^{0\nu} \] - nuclear matrix element
\[ F^{0\nu} \] - phase space integral depends on the Q value
\[ \langle m_{\beta\beta} \rangle \] - effective neutrino mass

\[ T^{2\nu}_{1/2} = 1.9 \times 10^{21} \text{ yr} \]
\[ T^{0\nu}_{1/2} = 10^{25} \text{ yr} \]
The Physics case

- $0\nu\beta\beta$ search probes physics beyond the SM
- LR symmetric models predict neutrino masses $>10$ meV even for NH
- Lepton number violation searches at LHC are focusing on heavy right-handed neutrino in the TeV range
- Most of the parameter space scrutinised at LHC is within the reach of next generation DBD experiments
GERDA status

- GERDA is located at LNGS, under 3500 m w.e. overburden
- Construction finished in 2009, operational since then
- GERDA is using HPGe detectors from germanium enriched in $^{76}$Ge. Source and detector is the same.

- **Status of Phase I**: data taking ended with 21.6 kg · yr exposure: run from Nov. 2011 to May 2013
- **Result of Phase I**: $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr
- **Goal of Phase II**: background level of $10^{-3}$ cts/(keV kg yr) and a half-life sensitivity of $\sim 10^{26}$ yr
- **Phase II strategy to reduce background**: LAr scintillation light readout + pulse shape discrimination
- **Phase II status**: data taking since 2015, first data release: June 2016
GERDA at Gran Sasso

- clean room with lock
- muon & cryogenic infrastructure
- control rooms
- water plant & radon monitor
- cryostat with internal Cu shield
- water tank, Ø10m, part of muon detector
Phase II setup

- 7 coaxial detectors, HdM and IGEX: 15.8 kg
- 30 new BEGe detectors, from new production total: 20 kg
- 3 natural coax: 7.6 kg
- Last integration test in Dec. 2015
- The experiment is alive since then
Upgrades for Phase II

- 30 new BEGe detectors need new holders
- New holder made of silicon plates
  - Silicon is cleaner
  - 3x less copper than in the Phase I holder
- Detector contacting with wedge bonding
- String wrapped in WLS coated nylon
  - Reduces $^{42}$K background
LAr - veto

Copper “shroud” with Tetratex reflector coated with TPB

3” low-background PMT
Hamamatsu R11065-20

SiPMs

Fiber “shroud” 800 m WLS fibre coated with TPB
LAr veto commissioning

- LAr-veto mounted in Nov. 2014, several calibration runs.
- Trigger on single photoelectron, both PMTs and SiPMs
- Very effective for gamma background

<table>
<thead>
<tr>
<th>Suppression of:</th>
<th>Ge Anti-Coincidence</th>
<th>LAr-veto</th>
<th>PSD</th>
<th>LAr + PSD</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{228}$Th</td>
<td>1.26 ± 0.01</td>
<td>97.9 ± 3.7</td>
<td>2.19 ± 0.01</td>
<td>344.6 ± 24.5</td>
<td>86.8%</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>1.26 ± 0.01</td>
<td>5.7 ± 0.2</td>
<td>2.98 ± 0.06</td>
<td>29.4 ± 2.5</td>
<td>89.9%</td>
</tr>
</tbody>
</table>
Pulse Shape Discrimination, Coax

- **Signal:** Single Site Event, **Background:** Multi-Site Event
- PSD can veto Multi-Site Events in HPGe detector
- Neural network trained with calibration data
- Achieved performance is similar to Phase I
- Tuned to 90% acceptance of the DEP of 2.6 MeV line (Tl-208)
Pulse Shape Discrimination, BEGe

- BEGe detectors have a better PSD performance
- A/E single parameter cut is very efficient rejecting multisite events
- Tuned to 90% acceptance of the $^{208}$Tl DEP peak
- ~85% acceptance for 2ν2β in the background data
Phase II performance

- Data released: Dec. 2015 - May 2016
- 85% duty cycle: Dec. 2015 - May 2016
- Exposure BEGe 5.8 kg yr
- Exposure Coax. 5.0 kg yr

- weakly calibration runs with Th-232 source
- Resolution at 2.6 MeV, BEGe: 3.2 keV
- Resolution at 2.6 MeV, Coax.: 3.8 keV
- Background data blinded $Q_{\beta\beta} \pm 25$ keV
Phase II, first results

- LAr-veto works for background data as well
- $K^{40}/K^{42}$ Compton continuum strongly suppressed by LAr-veto
- Data agrees with $T_{1/2}(2\nu\beta\beta) = 1.9 \times 10^{21}$ yr from GERDA Phase I
- $2\nu\beta\beta$ events are used to validate PSD and active volume determination
Phase II, first results

\begin{align*}
\text{counts / 30 keV} & \quad \text{energy [keV]} \\
10^3 & \quad 500 \quad 1000 \quad 1500 \quad 2000 \quad 2500 \quad 3000 \quad 3500 \quad 4000 \quad 4500 \quad 5000 \\
10^2 & \quad 1 \quad 10 \quad 2 \times 10 \quad 3 \times 10 \\
10 & \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1 \quad 1
\end{align*}

- **anti-coincidence cut (AC) + muon veto (MV)**
- **AC + MV + liquid argon veto (LAr)**
- **AC + MV + LAr + pulse shape discrimination (PSD)**

Enr. Coax: 5.0 kg·yr

\[3.10^{-3} \text{ cts/(kg·keV·yr)}\]
Phase II, first results

Enr. BEGe: 5.8 kg·yr

0.7 \times 10^{-3} \text{ cts/(kg\cdot keV\cdot yr)}
## Phase II, first results

<table>
<thead>
<tr>
<th>data set</th>
<th>exposure [kg yr]</th>
<th>FWHM [keV]</th>
<th>efficiency</th>
<th>final background [10^{-3} \text{ cnt/(keV kg yr)}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI golden</td>
<td>17.9</td>
<td>4.27±0.13</td>
<td>0.57±0.03</td>
<td>11±2</td>
</tr>
<tr>
<td>PI silver</td>
<td>1.3</td>
<td>4.27±0.13</td>
<td>0.57±0.03</td>
<td>30±10</td>
</tr>
<tr>
<td>PI BEGe</td>
<td>2.4</td>
<td>2.74±0.20</td>
<td>0.66±0.02</td>
<td>5_{-3}^{+4}</td>
</tr>
<tr>
<td>PI extra</td>
<td>1.9</td>
<td>4.17±0.19</td>
<td>0.58±0.04</td>
<td>4_{-2}^{+5}</td>
</tr>
<tr>
<td>PII coax</td>
<td>5.0</td>
<td>4.0±0.2</td>
<td>0.51±0.07</td>
<td>3_{-1}^{+3}</td>
</tr>
<tr>
<td>PII BEGe</td>
<td>5.8</td>
<td>3.0±0.2</td>
<td>0.60±0.02</td>
<td>0.7_{-0.5}^{+1.2}</td>
</tr>
</tbody>
</table>

- Exposure is calculated with total mass
- Efficiency includes: enrichment, active volume, 0νββ signal efficiency, PSD efficiency, LAr-veto dead time
- GERDA Phase II reached it’s background goal!
# Phase II, first results

<table>
<thead>
<tr>
<th></th>
<th>profile likelihood 2-side test stat.</th>
<th>Bayesian flat prior on cts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0\nu\beta\beta$ cts. best fit value</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$T_{1/2}(0\nu\beta\beta)$ lower limit [$10^{25}$ yr]</td>
<td>$&gt; 5.2$ (90% CL)</td>
<td>$&gt; 3.5$ (90% CI)</td>
</tr>
<tr>
<td>$T_{1/2}(0\nu\beta\beta)$ median sensitivity [$10^{25}$ yr]</td>
<td>$&gt; 4.0$ (90% CL)</td>
<td>$&gt; 3.0$ (90% CI)</td>
</tr>
</tbody>
</table>

- Unbinned profile likelihood: flat background + Gaussian signal
GERDA Phase II is taking data with 35.8 kg enriched germanium detectors

Phase II background goal reached: running practically background free:
- $0.7 \cdot 10^{-3} \text{cts/(keV} \cdot \text{kg} \cdot \text{yr)}$ achieved for BEGe data set
- Lowest background level in [cts/ROI] among all $0\nu\beta\beta$ experiments (10x lower than any running experiment)

New $T_{1/2}$ limit: Phase II + Phase I published + Phase I extra:
- Profile likelihood fit gives a median sensitivity of $4.0 \cdot 10^{25} \text{ yr}$
- And a half life limit of $5.2 \cdot 10^{25} \text{ yr}$

**Summary**