Status of the GERDA Experiment

Oliver Schulz
for the GERDA collaboration

IPA2012, May 13, 2013
$0\nu\beta\beta$-Decay

- Single $\beta$-decay not allowed for some isotopes, only double $\beta$-decay
- If $\nu$ is a Majorana Particle ($\nu = \bar{\nu}$), $0\nu\beta\beta$-decay must exist

\[
(T_{1/2}^{0\nu})^{-1} = G(Q, Z) |M_{\text{nucl}}|^2 \langle m_{ee} \rangle^2
\]

- Study of $0\nu\beta\beta$-decay can
  - Discover lepton-number violation
  - Determine nature of $\nu$ (Majorana or Dirac).
  - Give information about absolute Neutrino mass / hierarchy?
The Gerda Experiment

- Search for $0\nu\beta\beta$-Decay in $^{76}\text{Ge}$ at $Q_{\beta\beta} = 2039\text{keV}$
- Array of isotopically enriched HPGe detectors, suspended in liquid Argon
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  - Limit: $T_{1/2} > 1.9 \cdot 10^{25}$ y at 90% conf. HdM and IGEX
  - Claim: $T_{1/2} = 1.2 \cdot 10^{25}$ y Klapdor-Kleingrothaus et al., PL B586 (2004) 198
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- Ultra-low background setup, located underground at LNGS
- Currently running in Phase-I, designed to test Klapdor claim
- Phase-II will go beyond: Increased total detector mass, even lower background
The GERDA Collaboration

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

16 institutions
~100 members
Why use $^{76}$Ge?

Advantages:

- Source = Detector
- Production of enriched detectors up to 86% well established (though expensive)
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▶ HPGe has excellent energy resolution, important since:

$$T_{1/2} \propto \epsilon \cdot A \sqrt{\frac{M \cdot T}{b \cdot \Delta E}}$$

▶ Intrinsically pure

Challenges:

▶ For all $0_{\beta\beta}$ experiments:
▶ Must be well shielded from cosmics and external radiation
▶ Radio-pure setup, carefully select and screen all materials
▶ Detector operation under cryogenic conditions
▶ Cosmic activation of detector material ($\rightarrow ^{60}\text{Co}$ and $^{68}\text{Ge}$)
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The Gerda Setup
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Ge Detector Array
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- Water Tank / Muon Veto
- Ge Detector Array
- Liquid Argon Cryostat
The Gerda Setup

Water Tank / Muon Veto
Ge Detector Array
Liquid Argon Cryostat
Clean Room
Lock System
Gerda Phase-I Detectors

- 8 enriched coaxial detectors from HdM and IGEX (17.7 kg)
- 1 non-enriched coaxial detector (3.0 kg)
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- Since Spring 2012: 5 enriched Phase-II BeGe detectors (3.6 kg)
An Unexpected Background

- Observed background 10 × higher than expected
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- $^{42}\text{Ar} \rightarrow ^{42}\text{K}$, charged $^{42}\text{K}$ drift in E-field of detectors and decay there
- Copper mini-shrouds shield detector strings
Measurement of $^{76}\text{Ge} \ 2\nu\beta\beta$ Half-Life

\[ T_{1/2}^{2\nu} = \left(1.84^{+0.09}_{-0.08 \text{ fit}} \  0.06 \text{ syst}\right) \times 10^{21} \text{ yr} = \left(1.84^{+0.14}_{-0.10}\right) \times 10^{21} \text{ yr} \]
Phase-I Background

- Blinded window: 40 keV around $Q_{\beta\beta} = 2039$ keV
- Achieved background index: 0.02 cts/(keV kg yr) in ROI: 10 $\times$ better than HdM and IGEX

**No contribution at $Q_{\beta\beta}$:**
- $^{39}\text{Ar} (Q_{\beta} = 565$ keV), $^{40}\text{K}, ^{228}\text{Ac}$

**Contribution at $Q_{\beta\beta}$:**
- $^{42}\text{K} (^{42}\text{Ar}) \rightarrow Q_{\beta} = 3.5$ MeV, $E_{\gamma} = 2.4$ MeV
- $^{214}\text{Bi} (^{238}\text{U}) \rightarrow Q_{\beta} = 3.3$ MeV, $E_{\gamma} = 2.1, 2.2, 2.4$ MeV
- $^{208}\text{Tl} (^{232}\text{Th}) \rightarrow E_{\gamma} = 2.6$ MeV
- $^{60}\text{Co} \rightarrow Q_{\beta} = 2.8$ MeV
- $\alpha$-induced events (from isotopes in $^{238}\text{U}$ chain)
Have reached good understanding of background
Strong indications about location of $\alpha$-induced events
No details here - paper with detailed background decomposition coming soon
End of Phase-I and Unblinding

- Exposure target of 20 kg y reached
- Dataset for $0\nu\beta\beta$-Analysis (almost) frozen: Nov. 9 2011 to Apr. 15 2013, Live time of 456.15 days
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- Dataset for $0\nu\beta\beta$-Analysis (almost) frozen: Nov. 9 2011 to Apr. 15 2013, Live time of 456.15 days
- Unblinding in June, publication shortly after
- Data taking will continue for a short while
- Decommissioning of Phase-I setup in June, followed by maintenance and inspections of setup
Gerda Phase-II Upgrade

- After Phase-I decommissioning, installation of Phase-II
- 30 new BeGe-type HPGe detectors, additional mass of 20 kg
- Phase-I coaxial detectors (18 kg) will be re-used in Phase-II
Gerda Phase-II Upgrade

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- 30 new BeGe-type HPGe detectors, additional mass of 20 kg
- Phase-I coaxial detectors (18 kg) will be re-used in Phase-II
- New background target: 0.001 cts/(keV kg yr)
- Liquid-Argon instrumentation
  → active veto around detectors
BeGe Detectors for Phase-II

- BeGe: Broad-Energy Germanium Detector (Canberra)
- No bore-hole, small contact:
  - Small capacitance, higher energy resolution
  - Strong weighting field
**BeGe Detectors for Phase-II**

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- **Charges from different points → signals at different times**
Event Topology with BeGe Detectors

- Charges from different points $\rightarrow$ signals at different times
- Can separate single-site events (e.g. $0\nu\beta\beta$-decay) from multi-site event (Compton-scattering + X)

\[ 212 \text{Bi} \gamma \text{-line at } 1621 \text{keV} \]

- Double-escape peak (DEP): Mostly single-site events (simulates $0\nu\beta\beta$-decay)
- \[ 212 \text{Bi} \gamma \text{-line at } 1621 \text{keV} \]: Mostly multi-site events (simulates $\gamma$-background)
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D. Budjas et al., JINST 4P10007 (2009)

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- $^{212}\text{Bi}\gamma$-line at 1621 keV: Mostly multi-site events (simulates $\gamma$-background)

green: before PSA, blue: after PSA
BeGe Detector Production

- 2005: 37.5 kg GeO$_2$ produced by ECP, Zelengorsk, Russia
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[JINST 8 P04018]
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- All Ge transport in shielded shipping container (Water plus Steel shield)

[JINST 8 P04018]
$^{68}$Ge Activation During Production

Ge-68 Production in Diode 13137_P2476BB with 0.384 kg

- Zone refining
- Crystal growth
- Cherokee caverns
- Ship voyage
- "characterization"
- Slice cutting
- Grinding and diode production
- Storage at HADES

Time:
- 01Aug11
- 25Sep11
- 19Nov11
- 13Jan12
- 08Mar12
- 02May12
- 26Jun12
- 20Aug12
- 14Oct12
- 08Dec12
- 02Feb1
LAr Instrumentation, Design

- Liquid Argon scintillates - untapped potential
- Instrument LAr volume around detectors as BG veto
LAr Instrumentation, BG Reduction

[M. Heisel, PhD thesis]

- Effective background reduction, esp. for $\gamma$
Conclusions and Outlook

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- Full background decomposition to be published soon
- Unblinding of $0\nu\beta\beta$-ROI in June - Analysis will be ready
- Phase-II will add 20 kg of detector mass with new detector technology for background suppression
- Instrumentation of liquid argon around detectors will help to reach new background target: $10^{-3}$ cts/(keV kg yr)
Appendix
Alpha-Background Model

Gerda preliminary

- Po on surface
- Ra & daughters on surface
- Rn & daughters in LAr
Exponential Decay of $^{210}\text{Po}$ Background

$$T_{1/2} = 138.4 \pm 0.2 \text{d} \text{ fits perfectly}$$
Enriched vs. Non-Enriched Detectors

Counts/(keV kg yr)

-110
1
10
2

Energy (keV)

0 500 1000 1500 2000 2500

-\beta_{39}\text{Ar}

2\nu\beta\beta

Enriched coaxials, 13.65 kg x yr

Natural coaxials, 4.69 kg x yr

\beta_{214} 1765 keV

\beta_{214} 2204 keV

K-40 1461 keV

K-42 1525 keV

Tl-208 2614 keV

\nu_2
2νββ-Decay Publication History

- T_{1/2} (10^{21} yr)
- ITEP-YPI
- PNL-USC
- PNL-USC-ITEP-YPI
- HdM
- IGEX
- HdM-K
- HdM-B
- this work
- Barabash
- NNDC
- GERDA 12-12

Publication year:
- 1990
- 1995
- 2000
- 2005
- 2010
**GERDA physics goals**

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<tr>
<th>Phase</th>
<th>I</th>
<th>II</th>
</tr>
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<tbody>
<tr>
<td>Exposure [kg \cdot yr]</td>
<td>15</td>
<td>100</td>
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<tr>
<td>Bg [counts/(keV kg \cdot yr)]</td>
<td>$10^{-2}$</td>
<td>$10^{-3}$</td>
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<tr>
<td>Upper limit $m_{\beta\beta}$ [eV]</td>
<td>0.23-0.39</td>
<td>0.09-0.15</td>
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A. Smolnikov, P. Grabmayr PRC 81 028502(2010)

$\Delta L=2$

$\bar{\nu}_e=\nu_e$

$0\nu\beta\beta$ driven by exchange of light Majorana neutrinos

\[ Q_{\beta\beta} = 2039 \text{ keV} \]

\[ 2\nu\beta\beta \]

\[ 0\nu\beta\beta \]