Status and Progress of GERDA
‘The GERmanium Detector Array’

Karl Tasso Knöpfle
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on behalf of the GERDA collaboration
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Int. Workshop on Double Beta Decay & Related Neutrino Measurements (DBD09)
Hawaii, October 11 – 13, 2009
double beta decay

\(2\nu\beta\beta\)

- e\(^-\)  \(\overline{\nu}\)  e\(^-\)  \(\overline{\nu}\)
- \(A,Z\)  \(W^-\)  \(A,Z+2\)

conventional 2\(^{nd}\) order process
observed in various nuclei
\(T_{1/2} \sim 10^{19} - 10^{21}\) yrs

\(0\nu\beta\beta\)

- e\(^-\)  <\(m_{\beta\beta}\)> \(\neq 0\)
- \(\sum_i\overline{\nu}_i\)  \(\nu_i\)
- \(\sigma\)
- \(A,Z\)  \(W^-\)  \(A,Z+2\)

hypothetical process, \(T_{1/2} > 10^{25}\) yrs,
only possible if neutrino is massive Majorana particle
- lepton number violation \(\Delta L=2\)
- access to absolute \(\nu\) mass scale
- physics beyond s.m.
**Double Beta Decay**

2νββ

\[ e^- \quad \bar{\nu} \quad W^- \quad W^- \quad A,Z + 2 \]

conventional 2nd order process observed in various nuclei

\[ T_{1/2} \sim 10^{19} - 10^{21} \text{ yrs} \]

0νββ

\[ e^- \quad <m_{\beta\beta}> \neq 0 \quad \Sigma_i \quad \bar{\nu}_i \quad \nu_i \quad W^- \quad W^- \quad A,Z + 2 \]

hypothetical process, \( T_{1/2} > 10^{25} \text{ yrs} \), only possible if neutrino is massive Majorana particle

\[ \Delta L = 2 \] implies lepton number violation

\[ \text{access to absolute } \nu \text{ mass scale} \]

\[ \text{physics beyond s.m.} \]

Ge-76: \( Q_{\beta\beta} = 2039 \text{ keV} \)

sum of kinetic energies

observed

searched for

[Graph showing experimental signature with a peak at 2039 keV]
halflife – effective mass relation

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

- measured
- deduced

Diagram showing nuclear matrix elements for different isotopes:
- IBM–2 (Borea et al., 2009)
- QRPA (Simkovic et al., 2008)
- SM (Caurier et al., 2008)

Isotopes included: \(^{76}\text{Ge},^{82}\text{Se},^{100}\text{Mo},^{116}\text{Cd},^{128}\text{Te},^{130}\text{Te},^{136}\text{Xe},^{150}\text{Nd}\)

Schönert taup2009
### dbd isotopes in comparison

<table>
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<tr>
<th>isotope</th>
<th>$^{48}$Ca</th>
<th>$^{76}$Ge</th>
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(T_{1/2}^{0
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<td>$^{48}$Ca: 0.19% / 9.6% / $^{130}$Te: 35%</td>
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\[
(T_{1/2}^{0\nu})^{-1} = G_{0\nu}^{0\nu} (Q, Z) |M_{0\nu}|^2 \left( \frac{m_{ee}}{\langle m_{ee} \rangle} \right)^2
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**Experiment specific**

- **sensitivity**

\[
T_{1/2}^{0\nu}(n_\sigma) = \frac{4.16 \times 10^{26} y (\varepsilon a)}{n_\sigma} \left( \frac{W}{\langle W \rangle} \right) \sqrt{\frac{Mt}{b\Delta(E)}}
\]

- **detection efficiency**  
  \( =1 \) if source=detector

- **exposure** [kg y]

- **molecular weight of source**

- **instrumental spectral width**

- **background index** [cts/(keV kg y)]

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*RevModPhys 80(08)481

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DBD09, Oct 13

K.T.Knöpfle: 'GERDA'

6
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### Experiment specific

- **Sensitivity**
  
  \[
  T_{1/2}^{0\nu}(n_\sigma) = \frac{4.16 \times 10^{26} y}{n_\sigma} \left( \frac{\varepsilon a}{W} \right) \sqrt{\frac{M t}{b \Delta(E)}}
  \]

  Achieved with 76Ge

- **Detection efficiency** ( =1 if source=detector)
  
  86% 70 kg y exposure [kg y]

- **Molecular weight of source**
  
  3.3 keV

- **Instrumental spectral width**
  
  0.1

- **Background index [cts/(keV kg y)]**
  
  0.1

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*RevModPhys 80(08)481
Heidelberg – Moscow Experiment
5 enriched Ge-76 diodes (EPJ A12 ('01) 147)
background index ~0.1 cts/ (keV · kg · y)
35.5 kg y : $T_{1/2} \geq 1.9 \cdot 10^{25}$ y (90% CL)
$<m_{\beta\beta}> < 0.3 - 1$ eV
(similar limit by IGEX, NP B87 ('00) 278)
part of collaboration claims signal (PL B586 ('04) 198)
71.7 kg y : $T_{1/2} = 1.2 (0.7-4.2) \cdot 10^{25}$ (3σ range)
$<m_{\beta\beta}> = 0.44 (0.24 - 0.58)$ eV
Claimed 4σ significance dependent on background model (Strumia&Vissani '06, O. Chkvorets, PhD th. '08)

Cuoricino
62 TeO$_2$ bolometers (PR C7 ('08) 035502)
background index ~0.2 cts/ (keV · kg · y)
11.8 kg y : $T_{1/2} \geq 3.0 \cdot 10^{24}$ y (90% CL)
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Evidence remains unclear - confirmation needed with same & different isotopes
► reduce background by $O(100)$ for better sensitivity
GERDA goals & sensitivity

GERDA’s goal: reach background index at $Q_{\beta\beta} = 2039$ keV of $0.01 / 0.001$ cts / (keV·kg·y)

phase II:
add new enriched Ge-76 detectors, 20 kg
B $\sim 0.001$ cts / (keV·kg·y)
- 37.5 kg enriched Ge-76 bought
  3 y·35 kg exposure

phase I:
use Ge-76 diodes of HD-Moscow & IGEX
$\sim 18$ kg
B $\sim 0.01$ cts / (keV·kg·y)
intrinsic background expected

phase III: depending on results worldwide collaboration for real big experiment
  close contacts & MoU with MAJORANA collaboration
GERDA’s goal: reach background index at \(Q_{\beta\beta} = 2039\) keV of \(0.01 / 0.001\) cts / (keV \cdot \text{kg} \cdot \text{y})

**mass hierarchy**

- disfavoured by 0ν2β
- degenerate
- inverted
- normal

\(\Delta m^2_{23} < 0\)
\(\Delta m^2_{23} > 0\)

- phase II:
  - add new enriched Ge-76 detectors, 20 kg
  - \(B \sim 0.001\) cts / (keV \cdot \text{kg} \cdot \text{y})
  - ▶ 37.5 kg enriched Ge-76 bought
  - 3 y \cdot 35 kg exposure

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GERDA background reduction

EXTERNAL bgnds: $\gamma$(Th, U), n, $\mu$

INTRINSIC or VERY CLOSE bgnnds:
- cosmogenic - $^{60}$Co (5.3 a), $^{68}$Ge (270 d) - contaminated holders, FE, cables ...
GERDA background reduction

EXTERNAL bgnnds: $\gamma$(Th, U), n, $\mu$

Gran Sasso

LNGS: Laboratori Nazionali del Gran Sasso
GERDA background reduction

EXTERNAL bgnds: $\gamma$(Th, U), n, $\mu$

Shielding possible

INTRINSIC or VERY CLOSE bgnds:
- cosmogenic - $^{60}$Co (5.3 a), $^{68}$Ge (270 d)-contaminated holders, FE, cables ...

- water: $\gamma$ & n shield, Cherenkov medium for $\mu$ veto

- bare Ge diodes
  - source=detector

- stainless steel cryostat w/ Cu shield, Rn tight
  - also active shield!

- $\alpha$(LAr) = 0.050/cm
- $\alpha$(Cu) = 0.34/cm
- $\alpha$(H$_2$O) = 0.043/cm
- $\alpha$(Pb) = 0.48/cm
GERDA background reduction

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Shielding possible

INTRINSIC or VERY CLOSE bgnnds:
cosmogenic - $^{60}$Co (5.3 a), $^{68}$Ge (270 d) -
contaminated holders, FE, cables ...

Discriminate single & multi site events !
► SSE: $\beta\beta$, DEP
► MSE: Compton

bare Ge diodes
source=detector

stainless steel cryostat
w Cu shield, Rn tight
also active shield !

water: $\gamma$ & n shield,
Cherenkov medium
for $\mu$ veto

$\alpha$(LAr) = 0.050/cm  $\alpha$(Cu) = 0.34/cm
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anti-coincidence of detectors &
detector segments
pulse shape analysis (PSA)
GERDA bldg - rdy

cryo-mu-lab

clean room – rdy

phase I lock – under test

control room

water plant

Rn monitor

cryostat - rdy

FE electronics

under test

μ veto

rdy

phase I array

rdy (scaled:)

water tank - rdy

GERDA bldg - rdy

status

LAr fill : Oct/Nov 09
water tank:
Ø 10 m
h = 9.5 m
V = 650 m³

designed for external γ, n, μ background
~10⁻⁴ cts / (keV · kg · y)
construction of clean room
clean room, active cooling device getting prepared for installation
muon veto in water tank
R&D of GERDA Task Groups

- TG01  Modification & test of existing Ge diodes
- TG02  Design & production of new Ge diodes
- TG03  Front end electronics
- TG04  Cryostat and cryogenic infrastructure
- TG05  Clean room and lock system
- TG06  Water tank and water plants
- TG07  Muon veto
- TG08  Infrastructure & logistics
- TG09  DAQ electronics & online software
- TG10  Simulation & background studies
- TG11  Material screening
- TG12  Calibration

‘LArGe’ R&D - active LAr veto - topic of TG01
R&D of GERDA Task Groups

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'LaGe' R&D - active LaGe veto - topic of TG01  
JINST 3 (2008) P08007
cryostat

65 m³ volume for LN/LAr
200W measured thermal loss
active cooling with LN
internal copper shield
detailed risk analysis of
cryostat in ‘water bath’
leak before break principle
0.6g earth quake tolerant
certified pressure vessel
no penetrations below fill level
redundant safety systems
detailed radio assay
cryostat radio assay

1. Screening of all stainless steel sheet batches (13 x ~50kg) by underground γ spectroscopy at MPI-HD and LNGS (NIM A593 (2008) 448)

In 1.4571 material (X6CrNiMoTi17-12-2) total of 14 isotopes quantitatively identified including

Th-228 < 0.1 – 5, typically < 2 mBq/kg

much lower than expected – 10 mBq/kg!
► reduction of internal copper shield

2. MC deduced contribution to background index background

cryostat + copper shield + LAr shielding against external γ rays including water tank

< 2 \cdot 10^{-4} \text{ cts} / (\text{keV} \cdot \text{kg} \cdot \text{y})

0.1 \cdot 10^{-4} \text{ cts} / (\text{keV} \cdot \text{kg} \cdot \text{y})

( NIM A606 (2009) 790 )
3. Measurements of Rn emanation* at various fabrication/installation steps with MoREx**

- after 1./2. cleaning: $23\pm4 / 14\pm2$ mBq
- after copper mount: $34\pm6$ mBq
- after 3. cleaning: $31\pm2$ mBq
- after cryogenics mount: $55\pm4$ mBq

**evidence: $^{222}\text{Rn}$ concentrated in neck!

Rn shroud of 30 μm copper
Ø 0.8m, 3m height

to prevent convective transport
of Rn from walls/copper to Ge diodes

$BI \sim 1.5 \times 10^{-4}$ cts / (keV·kg·y)

* Uniform $^{222}\text{Rn}$ distribution of 8 mBq
implies $b = 10^{-4}$ cts/(keV kg y) in phase I.
**Appl.Rad.Isot. 52(2000) 691
p-type coaxial detectors

8 diodes (from HdM, IGEX) – total of 17.9 kg $^{76}$Ge

- all diodes refurbished, changed contacting scheme for improved operation in LN/LAr
- well tested procedures for mounting & handling
- FWHM at 1.33 MeV ~ 2.5 keV
- long term stability in LAr established

in addition:
6 former Genius-TF $^{nat}$Ge diodes
R&D: long term stability of Ge diodes in LN$_2$ / LAr

Apparent problem* of ‘Limited long-term stability of naked detectors in liquid nitrogen as result of increasing leakage current’ resolved by GERDA:

- operated 3 HPGe detectors in LN/LAr
- 2 years of experience, 50 cycles
  ▶ with proper procedure no problem in contradiction to claim*

* Klapdor-Kleingrothaus & Krivosheina, NIM A566 (2006) 472

![Graph showing leakage current over time](image)

- no deterioration after 1 year of operation in LAr
  M. Barnabé-Heider, PhD thesis ‘09

10 pA

100

50

0

γ irradiation

Time (min)

(no passivation (chosen design))

groove passivated

Leakage current (pA)

Days

DBD09, Oct 13

K.T. Knöpfle: 'GERDA'
Two technologies pursued:  1) n-type segmented  2) p-type BEGe

enriched & depleted Germanium

- 37.5 kg of 86% \textsuperscript{enr}Ge (in form of GeO\textsubscript{2}) in hand, stored underground at IRRM
- 84 kg of \textsuperscript{dep}GeO\textsubscript{2} acquired (relict of enrichment) and in use for tests

purification

- a solved problem (PPM Pure Metals, GmbH)
- no isotopic dilution
- total yield >90% for >6N quality
- total exposure at sea level < 3 days per purification
- negotiations for purification of enriched material started

crystal growing (n-type)

- natural Ge crystals pulled from 6N material by Institut für Kristallzüchtung, Berlin
- impurity density \(\sim 10^{11}\) to \(10^{13}\) cm\(^{-3}\), \(10^{10}\) cm\(^{-3}\) needed
- too high As concentration, to be reduced by refurbishing Czochralski puller
- recent alternative: p-type BEGe diodes from Canberra Belgium
R&D : pulse shape analysis (PSA)

Effect of electrode geometry on pulse-formation for a multi site gamma interaction

standard coaxial HPGe

‘modified electrode detector’
with ‘point contact’

Barbeau et al., nucl-ex/0701012v1

Non-segmented but powerful PSA
Most interesting candidate if mass production feasible
R&D: **Single / Multi Site Event discrimination**

**BEGe point-contact detector** – p-type (COTS of Canberra)

- **fractions after PSA cut**
  - D. Budjas, PhD thesis ’09
  - arXiv:0812.1735 [nucl-ex]
  - JINST, in press

**3x6-fold segmented coax detector** - n-type

- **fractions after single-segment & PSA cut**

- **fractions after PSA cut**
R&D: Single / Multi Site Event discrimination

BEGe point-contact detector
(COTS of Canberra)

fractions after PSA cut

D. Budjas, PhD thesis ’09
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Results so convincing that GERDA collaboration has ordered at Canberra
US/Belgium several crystals/ BEGe detectors made from the depleted Ge
► test of complete production chain

latest news of Oct 05:
first detector grade crystal pulled from the depleted Ge in Oak Ridge

similar / better suppression obtained for K-40, Co-60 & Ra-226 contaminations
test of full readout chain

3-channel PZ-0 ASIC
- built in AMS HV 0.8 μm CZX
- input JFET, $R_f$ & $C_f$ discrete

set up in Hall di Montaggio of LNGS:
clean bench for Ge handling
phase I lock prototype
test dewar with active cooling
prototype Ge-diode with final
mount, cabling & electronics

achieved: 2.9 keV with Co-60 source
test with 2 diodes in progress
• approved in 2005 by LNGS with its location in hall A,
• funded by BMBF, INFN, MPG, and Russia in kind
• construction completed in LNGS Hall A
• all phase I detectors (8 pcs, ~18 kg) refurbished & ready

► LAr fill of cryostat in Nov ’09 with subsequent start of commissioning / parallel R&D for phase II

goals:  
phase I : background 0.01 cts / (kg·keV·y)
► scrutinize KKDC result within ~1 year
phase II : background 0.001 cts / (kg·keV·y)
► $T_{1/2} > 1.5 \cdot 10^{26} \text{ y}$, $<m_{ee}> < 0.2 \text{ eV}$ *

* nucl. m.e. from Rodin et al.
The GERmanium Detector Array Collaboration

\(^a\) INFN Laboratori Nazionali del Gran Sasso, LNGS, Assergi, Italy
\(^b\) Institute of Physics, Jagellonian University, Cracow, Poland
\(^c\) Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany
\(^d\) Joint Institute for Nuclear Research, Dubna, Russia
\(^e\) Institute for Reference Materials and Measurements, Geel, Belgium
\(^f\) Max Planck Institut für Kernphysik, Heidelberg, Germany
\(^g\) Dipartimento di Fisica, Università Milano Bicocca, Milano, Italy
\(^h\) INFN Milano Bicocca, Milano, Italy
\(^i\) Dipartimento di Fisica, Università degli Studi di Milano e INFN Milano, Milano, Italy
\(^j\) Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
\(^k\) Institute for Theoretical and Experimental Physics, Moscow, Russia
\(^l\) Russian Research Center Kurchatov Institute, Moscow, Russia
\(^m\) Max-Planck-Institut für Physik, München, Germany
\(^n\) Dipartimento di Fisica dell'Università di Padova, Padova, Italy
\(^o\) INFN Padova, Padova, Italy
\(^p\) Physikalisches Institut, Eberhard Karls Universität Tübingen, Tübingen, Germany
\(^q\) Physik Institut der Universität Zürich, Zürich, Switzerland

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

~ 95 physicists from 17 institutions
the end