The search for neutrino-less double beta decay with GERDA @ LNGS: status and perspectives

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Astroteilchenphysik in Deutschland, 20-21. September, DESY Zeuthen
Status and perspectives of GERDA

Astroteilchenphysik in Deutschland, 20-21. September, DESY Zeuthen, S. Schönert, TU München

~ 100 members
19 institutions
6 countries

Groups from Germany:
Univ. Dresden, MPIK Heidelberg, MPP München,
TU München, Univ. Tübingen

a) INFN Laboratori Nazionali del Gran Sasso, LNGS, Assergi (BS), 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

- 100 members
19 institutions
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**Introduction: 0νββ**

Expected decay rate:

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

- Phase space integral
- Nuclear matrix element
- Effective neutrino mass
- Elements of (complex) PMNS mixing matrix

**Experimental signatures:**
- peak at \(Q_{ββ} = m(A,Z) - m(A,Z+2) - 2m_e\)
- two electrons from vertex

**Discovery would imply:**
- lepton number violation \(ΔL = 2\)
- \(ν’s\) are Majorana type
- mass scale & hierarchy
- physics beyond the standard model

**Ge-76:**
- \(Q_{ββ} = \)2039 keV

**2νββ**
Status and perspectives of GERDA

GERDA @ LNGS

clean room with lock

muon & cryogenic infrastructure

control rooms

Ge-detector array (enriched in $^{76}$Ge)

Ge-detector array

water plant & radon monitor

cryostat, Ø4m, with internal Cu shield

plastic µ-veto

water tank, Ø10m, part of muon-veto detector
1.1 μ/(m² h)

3400 m.w.e.
GERDA construction phase 2008-2010

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GERDA phased approach

The diagram illustrates the 90% probability lower limit $T_{1/2}$ for various exposure levels and background counts, compared to the KKDC claim. The curves represent different background levels, with the red curve showing the case of no background. The kkdc claim is highlighted by a purple line at the bottom of the graph.
GERDA phased approach

phase I:
use Ge-76 diodes of HD-Moscow & IGEX
~18 kg
BI ~ 0.01 cts / (keV·kg·yr)
intrinsic background expected
GERDA phased approach

**Phase II:**
- Add new enriched Ge-76 detectors, 20 kg
- $B_L \sim 0.001 \text{ cts} / (\text{keV} \cdot \text{kg} \cdot \text{yr})$
- 37.5 kg enriched Ge-76 bought
  - 35 kg $\times$ 3 yr exposure

**Phase I:**
- Use Ge-76 diodes of HD-Moscow & IGEX
- $\sim 18$ kg
- $B_L \sim 0.01 \text{ cts} / (\text{keV} \cdot \text{kg} \cdot \text{yr})$
- Intrinsic background expected
GERDA phase I detectors

8 diodes (from HdM, IGEX):
- Enriched 86% in $^{76}\text{Ge}$
- Total mass 17.66 kg

6 diodes from Genius-TF:
- $\text{nat}^{76}\text{Ge}$
- Total mass: 15.60 kg

- All diodes reprocessed and optimized for LAr
- Well tested procedure for detector handling
- Long term stability in LAr established
- Energy resolution in LAr: $\sim 2.5$ keV (FWHM) @1.3 MeV
1-string assembly for commissioning started June 2010

Commissioning runs with non-enriched low-background detectors to study performance and backgrounds (June 2010 – Mai 2011)

Energy resolutions during commissioning: dependent on chosen detector configuration:

- Coaxial (Phase I): 4-5 keV (FWHM) @ 2.6 MeV
- BEGe (Phase II): 2.8 keV (FWHM) @ 2.6 MeV

Calibration with $^{228}$Th:

- GTF 45:
- GTF 32:
- GTF 112:
1-string assembly for commissioning started June 2010

Calibration with $^{228}$Th:

Commissioning runs with non-enriched low-background detectors to study performance and backgrounds (June 2010 – Mai 2011)

Energy resolutions during commissioning:
- Coaxial (Phase I): 4-5 keV (FWHM) @ 2.6 MeV
- BEGe (Phase II): 2.8 keV (FWHM) @ 2.6 MeV

65μm Cu cylinder (‘mini-shroud’) to shield E-field
3-string assembly for phase I run

started Nov 2011

8 refurbished enriched diodes from HdM & IGEX
- 86% isotopically enriched in Ge-76
- 17.66 kg total mass
- plus 1 natural Ge diode from GTF

2 diodes shut off because leakage current high:
- total enriched enriched detector mass 14.6 kg
$^{228}$Th calibration once every one to two weeks; stability continuously monitored with pulser
calibration spectra
detector stability
muon veto

threshold, efficiency & stability

Measured PMT multiplicity w/o and with cut (>30) on number of detected p.e.

Veto efficiencies (threshold: 30 p.e.)
- 97.2% for all muons
- (99.1±0.4)% for muons with energy deposition in Ge
preliminary results

total energy spectrum

Cuts applied:
- Data quality (noise)
- Muon-veto
- Ge-Ge anti-coincidence

Blinded region: \((Q_{\beta\beta} \pm 20)\) keV

Visible backgrounds:
- Ar-39
- Alphas
- Indicated isotopes
- \(2\nu\beta\beta\) decay of Ge-76
preliminary results

Published activity of (1.01±0.08) Bq/kg (Benetti et al., NIM A574 (2007) 83) fully compatible with our data

Limit <41 μBq/kg (90% CL) (Ashtikov et al., arXiv:nucl-ex/0309001) NOT compatible with our data

Intensity of 1525 keV line in E-field free setup indicates Ar-42 activity to be more than twice the value of above limit

Evidence that charge K-42 ions drift in electric field of Ge-diodes.
Minishroud as shield against E-field
preliminary results

backgrounds: γ-line intensities

![Graph showing γ-line intensities for various isotopes.]

**GERDA / HdM intensity ratio typically 1/10**
preliminary results

energy spectrum: zoom to ROI

Background index usually evaluated in \((Q_{\beta\beta} \pm 100)\) keV (excluding blinded region of \((Q_{\beta\beta} \pm 20)\) keV)
preliminary results

GERDA / HdM BI ratio about 1/10
preliminary results

\[ T_{1/2}^{2\nu} = (1.88 \pm 0.10) \times 10^{21} \text{yr} \]
preliminary results

2νββ half life

\[ T_{1/2} / 10^{21} \text{ yr} \]

- PNL-USC
- PNL-USC-ITEP-YPI
- NdM 11 kg Y
- NdM 42 kg Y
- Bak.-HdM
- IGEX
- ENSDF evaluation
- Barabash*
- GERDA

6.1 kg y

* Evaluation by Barabash PR C81 (2010) 035501
Approximately 10 kg × years of data acquired until Sept. 2012
• GERDA Phase I expected completion in spring 2013: Unblinding & physics analysis

Subsequently start of GERDA Phase II:
• Goal: reduce background by factor >10 --
  (BI: 0.001 cts/(keV kg year))
• Up to additional 30 enriched BEGe detectors (20 kg)
• Liquid argon veto instrumentation
Status and perspectives of GERDA

Phase II detectors

novel thick window BEGe’s with advanced pulse shape performance

Signal shape provides clear topology for event-by-event signal ID / bgd discrimination:
- **SSE/MSE** discrimination
- **Surface** events:
  - n+ slow pulses
  - p+: ‘amplified’ current pulses

**Single-site** (0νββ-like)

**Multi-site** (bgd: γ FE peak)

**Amplitude [a.u.]**

**Time after trigger [ns]**

**Number of counts**

**Energy [keV]**

Budjas et al., JINST 4 P10007 (2009)
M. Agostini et al., JINST 6P03005 (2011)
After successful test of production production chain with $\text{depl} \text{Ge}$:

- 37.5 kg of 86% $\text{enr} \text{Ge}$ (in form of GeO2) purified to 35.4 kg (94%) of 6N (+ 1.1 kg tail = 97%).
Production of $^{\text{enr}}$Ge crystals at Oak Ridge (USA) October, 2011 – August 2012 completed

- 30 crystal slices (20.5 kg) produced and shipped
- Diode production on-going: 18 from 30 diodes produced
- End of 2012: up to 30 phase II (20 kg) detectors available
- Up to 15 kg residual $^{\text{enr}}$Ge material which needs chemical purification; production of 3rd batch considered

Transportation in shielded container to minimize cosmic ray activation

Ge stored underground storage when not processed
June: 5 enr BEGe Phase II detectors deployed in GERDA
Operation of Phase II detector prototype in LArGe:

**Measured** suppression factor at $Q_{\beta\beta}$: $\sim 0.5 \cdot 10^4$ for a $^{228}\text{Th}$ calibration source

Also: successful read out scintillation light with fibers coupled to SiPMs
Liquid argon instrumentation for Phase II

- Also: R&D on large area avalanche photodiodes and UV sensitive SiPMs to detect light inside MS
GERDA sensitivity

GERDA Sensitivity

$T_{1/2}$ 90% lower limit (yr)

- Current BL, 10 keV Window, 3.5kg BEGe 1/5/2012

11. Nov. 2011

11. Nov. 2011

Phase II

Sept 2012
Summary & outlook

- Novel cryogenic/water shield realized
- All subsystems running smoothly
- Phase I physics run started Nov 2011
- Region of interest (Q$_{\beta\beta}$±20 keV) blinded
- BEGe string since June
- Total data acquired up to date: ca. 10 kg years

**Preliminary results with 6 kg years exposure:**

$^{42}$Ar abundance factor >2 larger than 90% published limit
Best value for 2$\nu$\beta\beta decay of Ge-76 to be published soon
Best background index at Q$_{\beta\beta}$ of all Ge experiments so far
BI ≈ 0.02 cts / (keV×kg×yr) w/o pulse shape analysis
Goal: un-blind data spring next year and scrutinize KKDC result

**Perspectives for Phase II**

Approx. 20 kg (30 pcs) new enriched Ge diodes of BEGe type produced by end of year; superior PSA properties
Installation of LAr scintillation veto
Goal BI ≤ 0.001 cts / (keV×kg×yr)

$T_{1/2} > 1.5\times10^{26}$ yr, $0.09 < \langle m_{ee} \rangle < 0.15$ (PRC81 (10) 028502)

**Contingent on results:** world wide collaboration with Majorana for 1 ton experiment to explore few 10 meV mass range