Status and Perspective of the GERDA Neutrinoless Double Beta Decay Experiment

Karl Tasso Knöpfle
MPI Kernphysik, Heidelberg
on behalf of the GERDA collaboration
http://www.mpi-hd.mpg.de/GERDA

\[ T_{2\nu}^{1/2} = 1.74 \cdot 10^{21} \text{ yr} \]

\[ T_{0\nu}^{1/2} = ? \]

The 19th Particles and Nuclei International Conference (PANIC11)
Massachusetts Institute of Technology, Cambridge, July 24th – 29th, 2011
About 100 members, 19 institutions, 7 countries
Introduction

Construction and Status

Results from Commissioning Runs

Perspectives and Conclusion
Discovery of neutrinoless double beta decay would imply:
- Neutrino is its own anti-particle, has Majorana mass
- Access to absolute neutrino mass scale
- Lepton number violation $\Delta L = 2$
- Further new physics beyond the standard model

So far, best limits for neutrinoless double beta decay from Ge-76 experiments, IGEX and Heidelberg-Moscow (HdM), $T_{1/2} > 1.9 \cdot 10^{25}$ y at 90% confidence limit, as well as claim for evidence by part of HzM collaboration KKDC, PL B586 (04) 198 (71.7 kg\cdot y, BI $\sim 0.11$ cts/(keV\cdot kg\cdot y)
Reach background index (BI) at $Q_{\beta\beta} = 2039$ keV of $0.01 / 0.001$ cts / (keV $\cdot$ kg $\cdot$ y)

**Phase I**: use Ge-76 diodes of HD-Moscow & IGEX

$\sim 18$ kg

BI $\sim 0.01$ cts / (keV $\cdot$ kg $\cdot$ y)

Intrinsic background expected
Reach background index (BI) 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
BI $\sim 0.001$ cts / (keV·kg·y)
▷ 37.5 kg enriched Ge-76 bought
35 kg $\cdot$ 3 y exposure

**phase I:**
use Ge-76 diodes of HD-Moscow & IGEX
$\sim 18$ kg
BI $\sim 0.01$ 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 strategy:
underground site to suppress cosmics
improved shield against external radiation
discrimination between single- \((0\nu\beta\beta)\) & multi-site events
clean room with lock

control rooms

water plant & radon monitor

muon & cryogenic infrastructure

water tank, Ø10m, part of muon-veto detector

cryostat, Ø4m, with internal Cu shield

water
Introduction

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Results from Commissioning Runs

Perspectives and Conclusion
Construction delivery of cryostat

6 mar 2008
water tank roof
Construction

L’Aquila M=6.3 earthquake & aftershocks

6 April 2009

negligible impact in underground lab

LNGS galleria
0.03g

14.8m
0.52g peak ground acceleration
Construction

heat exchanger for active cooling & radon shroud

18 jul 2009
Construction

Muon veto instrumentation in water tank

August 2009

1 of 66 PMTs
Cryogenic system

Running smoothly since cryostat filled with LAr in December 2010. No refill needed since thanks to active cooling.

Water plant

Maintaining quality of ultra-pure water (resistivity >17MΩ·cm & TOC <20ppb) from BOREXINO.

Commissioning lock

Rigorously tested above ground in 2010 – working as expected.

Cleanroom and N₂ flushed clean bench

Running smoothly. Handling procedures of Ge diodes - never come in air! - well established.

Slow control

Collects data from all subsystems; web-based interface for global access.

Safety systems

Passed several realistic tests. Fast water drainage (<2 hours) verified.
Introduction

Construction and Status

Results from Commissioning Runs

Perspectives and Conclusion
Runs started in June 2010 using 3 refurbished Genius-TF \( ^{\text{nat}} \text{Ge} \)-diodes (7.61 kg)

NB ▶ p-type / coaxial ▶ ‘low background’ diodes

preamps (88K)

2.33kg

2.32kg

2.96kg

calibration: spectra with Th-228 radioactive source
run 12 (0.564 kg·y)
27 days run time
Fit compatible with 1Bq($^{39}$Ar)/kg

Data
Monte Carlo
Fit boundaries

Energy (keV)

counts/keV

$^{39}$Ar

‘understood’
Rather weak discrete lines from Th/U background, Th / U / $^{40}$K lines suppressed by factors of ~4 / ~4 / ~20 wrt HdM. 1525 keV line much stronger than expected,
GERDA proposal assumed: $^{42}\text{Ar} / ^{\text{nat}}\text{Ar} < 3 \cdot 10^{-21}$
Count rate of 1525 peak factor ~14 larger than expected.
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Additional inner shroud (IS) reduces counts by factor of 4-5. Still larger than expected! IS shields E-field and convection.

NB: Similar observations at $Q_{\beta\beta}$!
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Biasing IS/OS such that positive ions are attracted by IS: Count rate increases to about previous value.

▶ Clear evidence that $^{42}$K-ions drift in electric field. Potentially severe consequences for background at Q_{\beta\beta}! Field-free configurations desirable!
Ar-42 specific activity deduced from almost field-free runs 10-12

Published limit: <43 μBq/kg i.e. <4.3\cdot10^{-21} g/g at 90% CL (Barabash et al. 2002)
For homogeneous distribution BI ~0.007 expected – has big uncertainties. However, if $^{42}$K ions are collected at detector surface, BI increases.

The high energy spectral part is dependent on dead layer thickness.
Background rate significantly lower than in previous experiments (HdM, IGEX) - but still higher than Phase I goal of 0.01.

Background most probably not only due to $^{42}$Ar/$^{42}$K; could (partially) be due also to distant Th-232 source.  

► Background at $Q_{\beta\beta}$ not yet understood - better statistics needed!

Deduced background index in interval ($Q_{\beta\beta} \pm 200$) keV: $0.06 \pm 0.01$ cts/(keV·kg·y)
Most background between $^{39}$Ar endpoint & 1525 keV line accounted for by 2ν2β decays. (Basic background studies done better with non-enriched diodes.)
Introduction

Construction and Status

Results from Commissioning Runs

Perspectives and Conclusion
• Exploitation of pulse shape analysis

For Phase I detectors reduction of BI by a factor of up to 2 might be feasible. Blind analysis indispensable.
- Exploitation of pulse shape analysis
- Deployment of full array of enriched diodes

8 refurbished and tested diodes (HdM, IGEX) available
- 86% isotopically enriched in Ge-76
- 17.66 kg total mass
- 3-string lock under commissioning
- soon ready for start of Phase I physics run
• Exploitation of pulse shape analysis
• Deployment of full array of enriched diodes
• Order of phase II detectors

BEGe (point-contact) type of diode selected for Phase II – superb pulse shape discrimination!

Full production cycle tested with depleted material left over from enrichment process.

Enriched material reduced and purified. Negotiations for Phase II detector order in progress.
R&D for LAr instrumentation

- Exploitation of pulse shape analysis
- Deployment of full array of enriched diodes
- Order of phase II detectors
- Instrumentation of LAr for scintillation veto

Suppression factor at $Q_{\beta\beta}$ of ~5000 measured with Th-228 calibration source. Alternative to scintillation light readout by PMTs: fibers coupled to SiPMs.
• Construction completed.
• All subsystems commissioned and running smoothly.
• All phase I detectors (8 pcs, ~18 kg) refurbished & ready.
• Commissioning with natural and enriched Ge diodes in progress.

► $^{42}\text{Ar}$ isotopic abundance found to be about factor of 4 larger than 90% limit reported previously – serious background for phase II.

► Best background index at $Q_{\beta\beta}$ of all Ge experiments so far, but still factor 6 above phase I goal - not yet fully understood why. LAr instrumentation might be needed already to reach goal of phase I.

• Start of phase I physics run with enriched detectors soon.
• Full production chain tested for phase II BEGe detectors.
• Phase II detectors (~20 kg) to be ordered this year.

goals: phase I: background 0.01 cts / (keV·kg·y)
► scrutinize KKDC result within ~1 year
phase II: background 0.001 cts / (keV·kg·y)
► $T_{1/2} > 1.5 \cdot 10^{26}$ y, $0.09 < <m_{ee}> < 0.15$ eV

* PR C81(10)028502
Backup Slides
sensitivity* achieved with $^{76}\text{Ge}$

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

*RevModPhys 80(08)481

Heidelberg-Moskau Experiment.

KKDC: 71.7 kg·y: $T_{1/2} = 1.2 \times (0.7-4.2) \times 10^{25}$

$<m_{\beta\beta}> = 0.44 \times (0.24 - 0.58) \text{ eV (3\sigma)}$
GERDA: low Z shield, underground bare Ge diodes in high-purity LAr

MAJORANA: high Z, deep underground Ge diodes housed in vacuum cryostat, ultra-high-purity electroformed Cu shield

Water: γ & n shield, Cherenkov medium for μ veto

Stainless steel cryostat w Cu shield, Rn tight

10 cm electroformed Cu

45 cm lead

30 cm PE, active μ veto, Rn tight box

LAr can be also active shield!

\[ \alpha(LAr) = 0.050/cm \quad \alpha(Cu) = 0.34/cm \]
\[ \alpha(H_2O) = 0.043/cm \quad \alpha(Pb) = 0.48/cm \]
GERDA storage tanks

LAr for cool down and filling taken from storage tank.
started in June 2010 using 3 refurbished Genius-TF \textsuperscript{nat}Ge-diodes (7.61 kg)
NB ► p-type / coaxial ► ‘low background’ diodes
muon induced rate \( \sim 0.01 \text{ cts/(keV} \cdot \text{kg} \cdot \text{year}) \)

veto efficiency \( >94\% \) (system still incomplete)

started in June 2010

using 3 refurbished Genius-TF \( ^{\text{nat}}\text{Ge} \)-diodes (7.61 kg)

NB ➤ p-type / coaxial ➤ ‘low background’ diodes

Run12. Exposure: 0.525 kg \( \times \) year

- All events
- Muon veto
- Multiple-detector

**Date**

- 17-Feb
- 24-Feb
- 02-Mar
- 09-Mar

**Energy (keV)**

- 7000
- 6000
- 5000
- 4000
- 3000
- 2000
- 1000
- 0

PANIC11  28jul 2011  GERDA – status & perspectives  K.T.Knöpfle