GERmanium Detector Array – search for $0\nu2\beta$ decay

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0ν2β decay

0ν2β- only if:
\[\bar{\nu} = \nu \quad \text{Maiorana-particle}\]
\[\nu_r \leftrightarrow \nu_l \quad \text{other helicity} \quad \sim (1-(v/c)^2) \quad \text{for } m_\nu > 0\]

2ν2β-decay

\[\Delta L = 2\]

\[T_{1/2} (0\nu)^{-1} = G M^2 m_{\beta\beta}^2\]

effective neutrino mass

phase space

nuclear matrix element
$2\beta$-decay - $^{76}$Ge
Known knowns and known unknowns

knowns

neutrino-oscillations
nonzero neutrino mass
large mixing angles

unknowns:

absolute mass scale?
mass hierarchy?
Majorana- or Dirac?
…

\[ \nu = \nu \]
Neutrinos in Cosmology - structure formation

$$\Omega_{\text{matter}} \sim 0.30$$

$$\Omega_{\nu} < 0.02$$

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$$\Sigma m_{\nu_i} < 1 \text{eV}$$
0ν2β decay – effective neutrino mass $m_{\beta\beta}$

$0\nu2\beta$-decay \( \propto |\langle m_{\beta\beta} \rangle| = |\sum m_i U_{ei}^2|$

$m_{\beta\beta} = |m_{\beta\beta}^{(1)}| + |m_{\beta\beta}^{(2)}| \cdot e^{i\Phi_2} + |m_{\beta\beta}^{(3)}| \cdot e^{i\Phi_3}$

\[
|m_{\beta\beta}^{(1)}| = |U_{e1}|^2 m_1 \\
|m_{\beta\beta}^{(2)}| = |U_{e2}|^2 \sqrt{m_1^2 - \Delta m_{21}^2} \\
|m_{\beta\beta}^{(3)}| = |U_{e3}|^2 \sqrt{m_1^2 + \Delta m_{31}^2}
\]

solar $\Rightarrow |U_{e1}|^2, |U_{e2}|^2, \Delta m_{21}^2$

atmosph. $\Rightarrow |\Delta m_{31}^2|$

CHOOZ $\Rightarrow |U_{e3}|^2 < 0.05$

$\Rightarrow$ unknown parameters: $m_1$, sign($\Delta m_{31}^2$), CP-phases $\Phi_2, \Phi_3$
Sensitivity of $0\nu2\beta$ - decay search

**theory:**

$$T_{1/2} (0\nu) = (G M^2 m_{\beta\beta}^2)^{-1}$$

**experiment:**

$$T_{1/2} (0\nu) > 4.2 \cdot 10^{26} y \cdot \varepsilon \cdot (a/A) \cdot \sqrt{Mt/B \Delta E}$$

$$m_{\beta\beta} < \sqrt{\frac{\sqrt{B \Delta E / Mt}}{\varepsilon a}}$$

$$\approx 1 / \sqrt{T_{1/2} (0\nu)}$$

- $\varepsilon$ - detection efficiency at $Q_{\beta\beta}$
- $a$ - $\beta\beta$ isotope fraction
- $M$ - mass of detector in kg
- $t$ - measurement time in years
- $B$ - background in cts/(keV kg y)
- $\Delta E$ - FWHM energy resolution at $Q_{\beta\beta}$ in keV
- $A$ - mass number
Sensitivity of $0\nu2\beta$ - decay search

$$m_{\beta\beta} < \sqrt{\frac{\sqrt{B \Delta E}}{\varepsilon_a} / M_t}$$

Germanium $\Rightarrow$ Detector $=$ Source
high $\varepsilon$ - detection efficiency at $Q_{\beta\beta}$
as large as possible number of target atoms
enrichment of $^{76}\text{Ge}$ to 86% $\Rightarrow$ high $a$ - $\beta\beta$ isotope fraction
large array (up to 100 kg) $\Rightarrow$ large $M$ - mass of detector in kg
germanium Detectors
$\Rightarrow$ very good $\Delta E$ - FWHM energy resolution
Long measurement time $t$

REDUCE BACKGROUND $B$ !!!!!
Sensitivity of $0\nu2\beta$-decay search

\[ m_{\beta\beta} < \sqrt{\frac{\sqrt{B \Delta E / Mt}}{\epsilon a}} \]

state of the art for Ge before GERDA

**IGEX, Heidelberg-Moscow experiments**

\[ Mt = 71.7 \text{ kg y} \]
\[ B = 0.11 / \text{(keV kg y)} \]
\[ a = 86\%, \epsilon \sim 1, \Delta E \sim 3 \text{keV} \]

Sensitivity

\[ T_{1/2} \sim 2 \times 10^{25} \text{y} \]
\[ m_{\beta\beta} < 350 \text{ meV} \]

Claim of Evidence!

to test and to improve
- increase Mt
- reduce background B

\[ \Rightarrow 1 \text{ ton of isotopes and } B < 10^{-3} / \text{(kg y)} \]
for 10 meV scale
GERDA - Idea

Hd-Moscow background given by:
- detectors surroundings
- cosmogenic activation of Ge

GERDA - Phase 1:
bare detectors in purified liquid Argon and low Z shield
GERDA - Idea

Hd-Moscow background given by:
- detectors surroundings
- cosmogenic activation of Ge

GERDA - Phase 2:
reduce cosmogenic background by event recognition:
segmented detectors and/or pulse shape
+ increase $^{76}\text{Ge}$-mass

$0\nu2\beta$ – events are single site
Co background are multiple site
GERDA - set up at Gran Sasso

from outside to inside

Water tank:
- Gamma shield
- Neutron shield
- Muon Veto

Cryostat:
- contains liquid Ar
- additional Cu shield inside

Liquid Argon provides:
- pure ‘inner‘ shielding
- operating T for detectors

Bare Ge detectors
support structure as
light as possible
detectors hold by strings

low Z materials, liquids can be purified, ...

64 m$^3$ of liquid Ar, 650 m$^3$ of water,
4m Ø steel cryostat, 10 m Ø water tank
GERDA - set up at Gran Sasso

- Stainless steel cryostat: 25t, $U/Th < 5 \text{mBq/kg}$
- Internal Cu shield: 20t, $U/Th < 16 \text{mBq/kg}$
- Radon Shroud inside Cryostate to avoid Rn convection to Ge detectors

- Ge detector array:
  - made up of detector strings
  - in the center of the LAr-cryostat
GERDA - Phases

GERDA - Phase I:
- 18 kg $^{76}$Ge (existing from Hd-M and IGEX)
- 15 kg $^{29}$NatGe
- background $10^{-2}$ / (keV kg y)
- test claim within 1 year
  ( 6cts with 0.5 cts bckgrd )

GERDA - Phase II:
- new segmented or BeGe detectors
  ⇒ adds > 20kg $^{76}$Ge
  ⇒ distinguish multi site / single site
- several detectors depleted in $^{76}$Ge
- background $10^{-3}$ / (keV kg y)
  ( = 1 count / (keV ton year) !!!)

GERDA - Phase III:
- ~1 ton $^{76}$Ge
- world wide GERDA-MAJORANA collaboration
- background 0.1 / (keV ton y)
- test inverted neutrino mass hierarchy
- $m_{\beta\beta}$ ~ (some) 10meV
Long term stability test of HPGe detectors in LAr

- $\Delta E \sim 2.5$ keV, leakage current stable
- problems reported by GENIUS TF
  overcome by GERDA (different detector types)

IGEX and HdM crystals

- removed from vacuum cryostats
- refurbished by Canberra
- less than 1 week above ground
- new low mass holders
- now stored at LNGS
  in vacuum containers
GERDA – Status – Phase II detectors

Preparation of 18 fold segmented detectors
- novel ‘snap’ contact
- only small amount of extra material (a few 10g / detector)
- successfully tested

http://wwwgerda.mppmu.mpg.de/
GERDA – Status – Phase II detectors

Detector in vacuum exposed to Th228 source

<table>
<thead>
<tr>
<th>sample</th>
<th>data</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co60</td>
<td>14.2 ± 2.1</td>
<td>12.5 ± 2.1</td>
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<tr>
<td>Th228</td>
<td>1.68 ± 0.02</td>
<td>1.66 ± 0.05</td>
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(Double-escape peak (single-site dominant)
1620keV Bi212 (multi-site dominant)

(depending on source position)
Phase-II detector candidate: point-contact detector
- enhanced efficiency for low-energy gammas (BeGe)
- low capacitance (⇒ low noise)
- position dependent pulse shape

Canberra thick window broad energy detector (BEGe, 878g)

- Successful R&D
  ✓ Observed complete charge collection from full detector volume.
  ✓ No position dependence of pulse height and resolution.
  ✓ Similar reduction factor achieved.
- BEGe production yield under investigation.
GERDA – Set up at Gran Sasso – Cryostat 03/08
GERDA – Set up at Gran Sasso – Water Tank 06/08
GERDA – Set up at Gran Sasso – Clean Room 05/09
GERDA – Set up at Gran Sasso – Muon Veto 06/09

Inside the water tank
GERDA – Outlook

Commissioning of GERDA set up at Gran Sasso will start in 2009

Phase I (2009-2011):
After 1 year data taking (~ 15 kg y) with background $10^{-2}$ / (keV kg y)
⇒ GERDA can confirm or refute claim of $0\nu 2\beta$ observation

\textbf{Limit: half live } $T_{1/2}(0\nu) > 3 \times 10^{25} \text{ y, } m_{\beta\beta}^{QRPA, SM} < (0.2 - 0.5) \text{ eV}$

Phase II (starting 2011):
- Total $^{76}\text{Ge}$ mass of 40kg
- Background reduction by segmented detectors and/or PSA
- After exposure of 100 kg y with background $10^{-3}$ / (keV kg y)
⇒ test degenerate neutrino mass regime

\textbf{Limit: half live } $T_{1/2}(0\nu) > 1.5 \times 10^{26} \text{ y, } m_{\beta\beta}^{QRPA, SM} < (0.1 - 0.2) \text{ eV}$

Phase III (proposed to start 2014):
- GERDA – MAJORANA collaboration
- mass of $^{76}\text{Ge}$ at 1 ton scale
- background reduction to $10^{-4}$ / (keV kg y)
⇒ test inverted neutrino mass regime
GERDA – Collaboration

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~97 scientists.