Search for neutrinoless double beta decay beyond $10^{26}$ yr half life sensitivity with GERDA

Rizalina Mingazheva
30th August 2018
Aims of $0\nu\beta\beta$ decay search

Some open question in neutrino physics:

- What is the mass of $\nu_{\text{lightest}}$?
- What is the neutrino mass hierarchy?
- Are neutrinos Dirac or Majorana particles?
- Is lepton number violated in nature?

$0\nu\beta\beta$ -decay

- $A(Z, N) \to A(Z+2, N) + 2e^-$
- Hypothetical non-SM process, $\Delta L=2$
- The signature: peak at the end-point of electrons energy spectra, at $Q_{\beta\beta}$
Search for the $0
\nu\beta\beta$ decay

The observation is possible for $O(10)$ nuclei

• For expected background rate, BI:

$$T_{1/2}^{0\nu} \propto \epsilon \sqrt{\frac{Mt}{BI \cdot \Delta E}}$$

• Background-free case:

$$T_{1/2}^{0\nu} \propto \epsilon \cdot Mt$$

Mt - exposure
BI - backgr. index  $\epsilon$ - detection efficiency

$^{76}$Ge detectors

• High intrinsic purity
• Best energy resolution (3 - 4 keV FWHM at $Q_{\beta\beta}$ ($\approx 2039$ keV))
• 88% enrichment of $^{76}$Ge
GERDA data taking

- Phase II since Dec. 2015:
  - Nature 544, 47–52
  - Phys. Rev. Lett. 120, 132503
  - Neutrino2018 - focus of this talk

- Total collected exposure: 82.4 kg·yr
The GERDA experiment

- Located at the LNGS underground laboratory
  - 3.5 km w.e. of rock

1. Water tank, muon veto
2. Clean room
3. Plastic muon veto system
The GERDA experiment

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4. Liquid Argon (LAr) veto system
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5. Detector array

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6. Detector module
Germanium detectors in GERDA

- In GERDA: Semi-Coaxial, broad energy germanium (BEGe) detectors
- Signal readout from $p^+$ - contact: charge collection due to electric potential created by depletion voltage

Background rejection

In coincidence with Ge-detectors, Muon and LAr veto

Only events with the energy deposition in a single detector remain
Pulse Shape Discrimination

There are still γ with energy deposition in multiple location or α on the surface.

Pulse Shape Discrimination (PSD) \cite{Eur. Phys. J. C 73 (2013) 2583}
- Charge ∼ energy of the event
- Pulse shape depends on event topology

\[ \begin{align*}
\text{Charge (E) [a.u.]} & \rightarrow \\
\text{Current (A) [a.u.]} & \rightarrow \\
\text{Normalised A/E} & \\
A/E & \sim 1 \\
A/E & < 1
\end{align*} \]
Energy calibration

- Determine energy scale and resolution
- Weekly exposure to $^{228}$Th sources: $O(100)$ calibrations for the Phase II
- Monitor detectors stability with gamma line from $^{208}$Tl decay at 2.6 MeV

Resolution at $Q_{\beta\beta}$:
- Coaxial: FWHM = $3.6 \pm 0.1$ keV
- BEGe: FWHM = $3.0 \pm 0.1$ keV
**GERDA Phase II spectra**

- Blind analysis in $Q_{\beta\beta} \pm 25$ keV
GERDA Phase II spectra

- Blind analysis in $Q_{\beta\beta} \pm 25$ keV
- After LAr veto
GERDA Phase II spectra

- Blind analysis in $Q_{\beta\beta} \pm 25$ keV
- After LAr veto
- After PSD cut
Energy spectra in ROI

Region of Interests (ROI): $Q_{\beta\beta} \pm 25$ keV

BI is estimated from 1930 - 2190 keV

- Enriched BEGe:
  - BI: $5.6^{+3.4}_{-2.6} \cdot 10^{-4}$ cts/kg·yr

- Enriched Coaxial:
  - BI: $5.7^{+4.1}_{-2.6} \cdot 10^{-4}$ cts/kg·yr

Half life sensitivity does not depend on the BI $\rightarrow$

GERDA is effectively "background free" experiment
Unblinding of ROI

Few events in the opened box

Unbinned maximum likelihood fit:
• Best fit value for zero $0\nu\beta\beta$ events
• Frequentist: $T_{1/2}^{0\nu} > 0.9 \cdot 10^{26}$ yr. (90% C.L.)
Median sensitivity: $1.1 \cdot 10^{26}$ yr. (90% C.L.)!
LEGEND is coming

- Joint effort from GERDA and Majorana collaborations
- Combine the best of the developed techniques
- **LEGEND-200:**
  - 200 kg of active mass
  - New type of the detectors are currently being tested
  - Location at LNGS
  - Existing GERDA infrastructure
  - BG goal: $0.6 \cdot 10^{-3}$ cts/(FWHM·kg·yr)
  - Will start in 2021
- **LEGEND-1000:**
  - Location TBD
  - Existing GERDA infrastructure
  - BG goal: $0.1 \cdot 10^{-3}$ cts/(FWHM·kg·yr)
  - The start is connected to funding
Conclusion and outlook

GERDA:
- Dec. 2015: PhaseII
- "Background free"
- Excellent FWHM: 2‰ at $Q_{\beta\beta}$

In the near future:
- LEGEND-200: almost fully funded
  - will reach sensitivity of $10^{-29}$
  - start in 2021
- LEGEND-1000: the goal is to reach
  - sensitivity of $10^{-27}$

Excellent FWHM: 2‰ at $Q_{\beta\beta}$
Conclusion and outlook

GERDA:
- Dec. 2015: PhaseII
- "Background free"
- Excellent FWHM: $2\%$ at $Q_{\beta\beta}$

In the near future:
- LEGEND-200: almost fully funded will reach sensitivity of $10^{27}$ yr start in 2021
- LEGEND-1000: the goal is to reach sensitivity of $10^{28}$ yr

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GERDA 18-03

**Search for neutrinoless double beta decay with GERDA**

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Thank you!
Bonus slides
GERDA data taking

- Phase II since Dec. 2015:
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  - Phys. Rev. Lett. 120, 132503
  - Neutrino2018 (by A. Zsigmond) - in the focus of this talk
- Total collected exposure: 82.4 kg·yr

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On the mbb and NME
On the mbb and NME

![Graph showing sensitivity versus exposure](image)

- $T_{1/2}^{\nu}$ vs. exposure (90% C.L.)
- BI = 0 cts/(keV kg year)
- BI = $10^{-3}$ cts/(keV kg year)
- BI = $10^{-2}$ cts/(keV kg year)
- BI = $10^{-1}$ cts/(keV kg year)

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Effective Majorana mass

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