Search for neutrinoless double beta decay with the GERDA experiment

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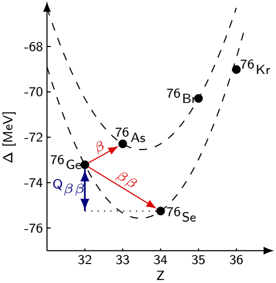
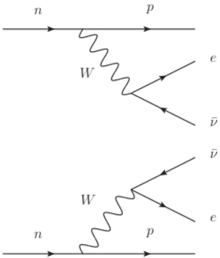
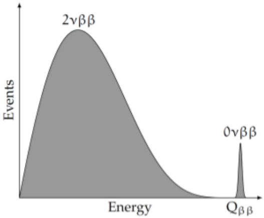
on behalf of the GERDA collaboration

Kitzbühel
28.06.2016

Double Beta Decay



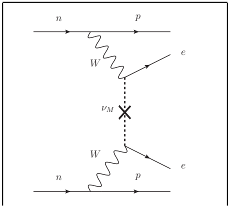


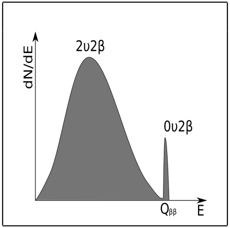


$(\mathrm{A, Z}) \rightarrow (\mathrm{A, Z} + 2) + 2e^- + 2\bar{\nu}_e$

- weak second order SM process
- $2\nu 2\beta$ might be observable in some even even nuclei where beta decay is energetically forbidden
- has been observed for eleven nuclei
- 4 particles in final state $\rightarrow$ $\beta\beta$ spectrum is a continuum ending at the Q-value.
- Experimentally observed in 12 isotopes $T_{1/2}^{2\nu\beta\beta} \approx (10^{18} - 10^{24})\mathrm{yr}$

Neutrinoless Double Beta Decay





$(A, Z) \rightarrow (A, Z+2) + 2e^{-}$

- non-SM process, $\Delta L = 2$
- possible only if neutrinos have Majorana mass component
- 2 particles in final state
  $\rightarrow$ signature is peak at $Q_{\beta\beta}$(^{76}Ge: 2039 keV)

Expected decay rate

$$\left(T_{1/2}^{0\nu}\right)^{-1} = G^{0\nu}(Q, Z) \cdot \left|\mathcal{M}^{0\nu}\right|^{2} \cdot < m_{\beta\beta} >^{2}$$

$$G^{0\nu}(Q, Z) = \text{phase space integral}$$

$$\left|\mathcal{M}^{0\nu}\right|^{2} = \text{nuclear matrix element}$$

$$\langle m_{\beta\beta} >^{2} = \text{effective neutrino mass}$$

What can we learn from $0\nu\beta\beta$?

- Neutrinos have Majorana mass component
- Absolute neutrino mass scale and mass hierarchy

Search for $0\nu\beta\beta$ Decay

Project	Isotope	Location	Status
GERDA	^{76}Ge	LNGS	Phase I completed Phase II is taking data
Cuore	^{130}Te	LNGS	Commissioning
Majorana Demonstrator	^{76}Ge	SURF	Commissioning
SuperNEMO Demonstrator	^{82}Se	LSM	R&D, Construction
SNO+	^{130}	SNOLAB	R&D, Construction
CANDLES	^{48}Ca	Kamioka	R&D, Construction
Cobra	^{116} Cd	LNGS	R&D
Lucifer	^{82}Se	LNGS	R&D
DCBA	many	[Japan]	R&D
AMoRE	^{100}Mo	[Korea]	R&D
MOON	^{100}Mo	[Japan]	R&D

Experimental sensitivity

- Zero background

$$T_{1/2}^{0\nu\beta\beta} \propto e \cdot a \cdot M \cdot t$$

- Non-zero background

$$T_{1/2}^{0\nu\beta\beta} \propto e \cdot a \sqrt{\frac{M \cdot t}{BI \cdot \Delta E}}$$

a = isotopic abundance

e = total efficiency

M = detector mass

$t$live time

$M \cdot t$ = exposure

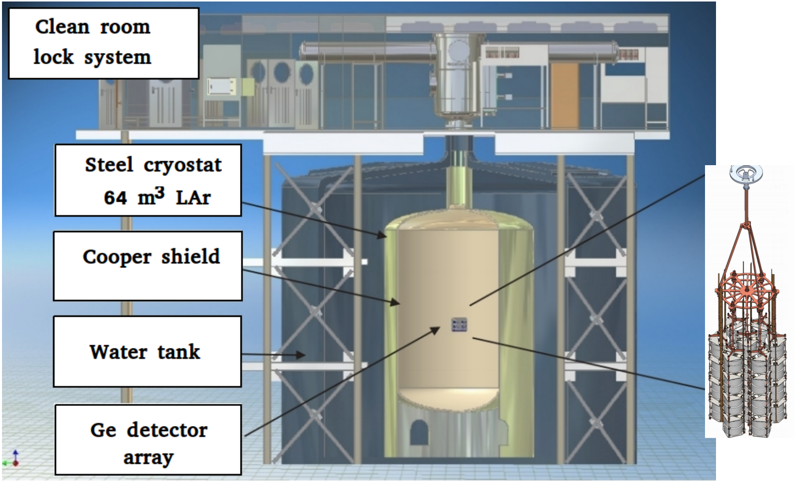
BI = Background Index

ΔE = energy resolution

^{76}Ge detectors

- Well established detector technology
- High intrinsic purity
- High total efficiency: $\varepsilon \sim 0.75$
- Best energy resolution on the market: ~ 1.5‰ FWHM at $Q_{\beta\beta}$
- Typically enriched to 86% in ^{76}Ge

The GERDA Experiment



- Located in Hall A at Laboratori Nazionali del Gran Sasso of INFN
- 3500 mwe overburden (μ flux $\sim 1\ \mathrm{m}^{-2}\mathrm{h}^{-1}$))
- Array of bare Ge detectors 86% enriched in ^{76}Ge directly inserted in liquid argon (LAr)
- Low mass, high purity holders, cables and front-end electronics

Signal and background events topology

Signal

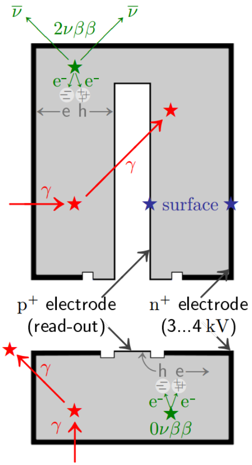
Localized energy deposition within ≈ 1mm in one detector (Single Side Events [SSE])

Background

- Multiple energy deposition in one detector (Multi Side Events, removed by Pulse Shape Discrimintaion [PSD])
- Events with coincident energy deposition in the LAr (active veto)
- Energy deposition in multiple detectors (developed anti-coincedence cuts)

Surface events

- fast (p^+) and slow (n^+) rising signals (PSD)



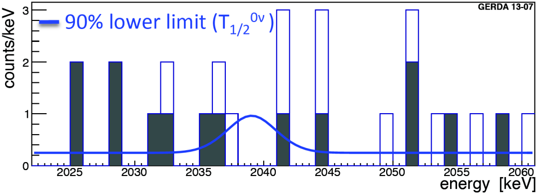
GERDA Phase I

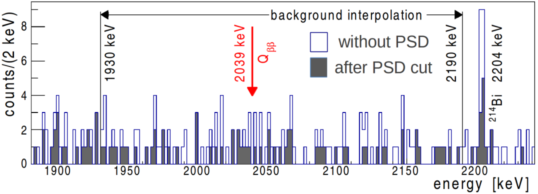
Nov 2011 - May 2013

- 15 kg of ^{76}Ge
- Live time: 1.5 yr
- Exposure: 21.6 kg·yr
- Blind analysis in the ROI $Q_{\beta\beta}\pm5$keV
  N exp $= 2.0 \pm 0.3$
  N obs $= 3$ events
  Profile likelihood: the best fit for $N_{0\nu}=0$
- No counts in 2039 keV$\pm1\sigma$

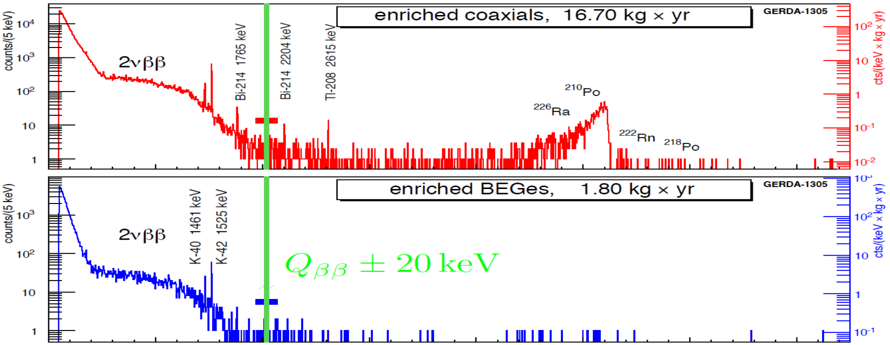
BI $1{\cdot}10^{-2}$ cts/(keV·kg·yr)

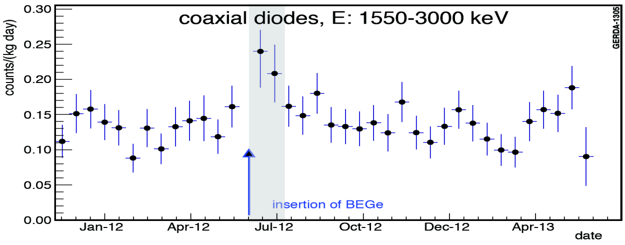
$T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}$yr





The Background of GERDA Phase I





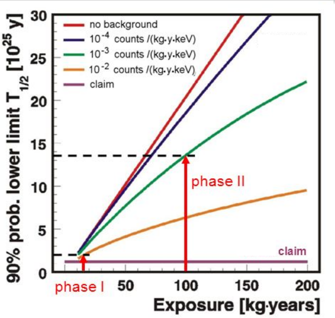
Background

- top: before the application of PSD
- left: time development of the Phase I background index

GERDA Phase II: Launch 25th of Dec 2015

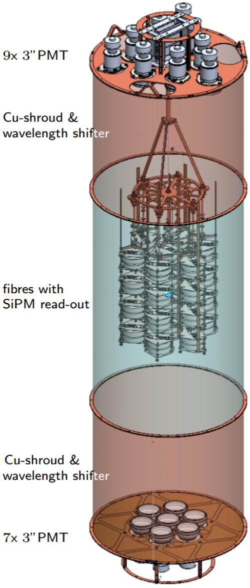
Minimization of the BI at $Q_{\beta\beta}$

- Reduce close background sources: cleaner signal and HV cables, reduce materials for detector holders
- Special care in crystal production and handling
- BEGe detectors for enhanced PSD
- Install PMTs and SiPMs to detect LAr scintillation light and reject external background



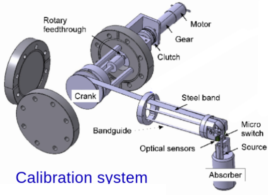
BEGe detectors

- Cylindrical, point-contact detectors
- Better energy resolution
- More effective PSD

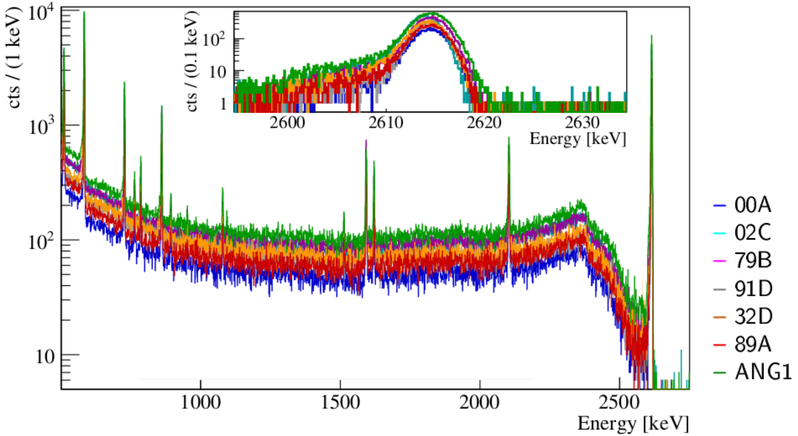


GERDA Phase II. Energy calibration

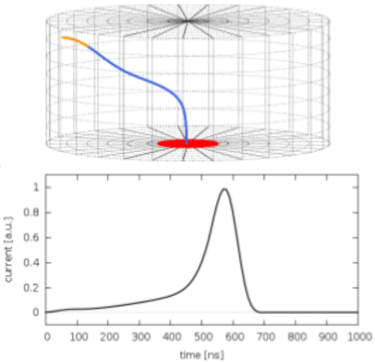
- Calibration is performed weekly using ^{228}Th source
- $FWHM^{FEP}_{BEGe} = 3.4 \pm 0.2$
- $FWHM^{FEP}_{Coax} = 4.2 \pm 0.2$

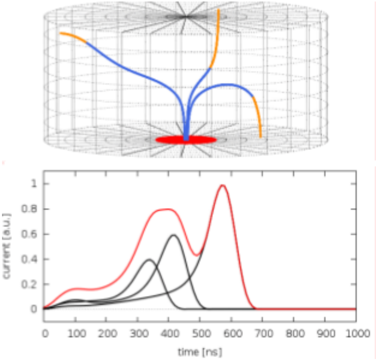


Calibration system



Gerda Phase II. PSD over A/E study



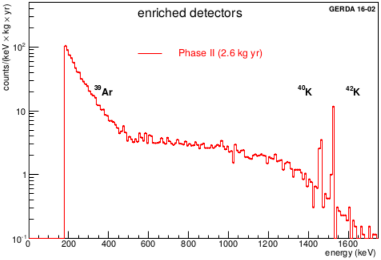


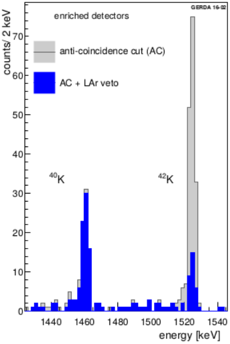
A/E method

- allows to discriminate between signal and background
- tuned using double escape peak (DEP)of ^{208}Tl (A/E=1), compton continuum and $2\nu\beta\beta$ events
- keep events with $0.965 < A/E < 1.07$
- acceptance for $0\nu\beta\beta = (92 \pm 2)\%$

GERDA Phase II. First look at the physics data

Efficient background supression by LAr veto

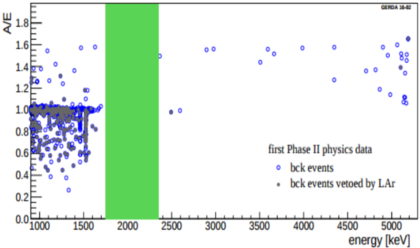




- By February 2016 - exposure 2.6 kg yr
- Dead time due to LAr veto $< 2\%$

By 1st of June..

- Exposure:10.8 kg·yr



Coming soon...

- Phase II unblinding results [seminar by B. Schwingenheuer 29th of June @ LNGS]

Conclusion

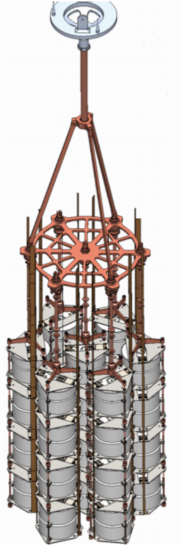
Phase I

- Sucessfully has been completed in May 2013
- Exposure 20 kg·yr
- 15kg of ^{76}Ge
- BI $1{\cdot}10^{-2}$ cts/(keV·kg·yr)

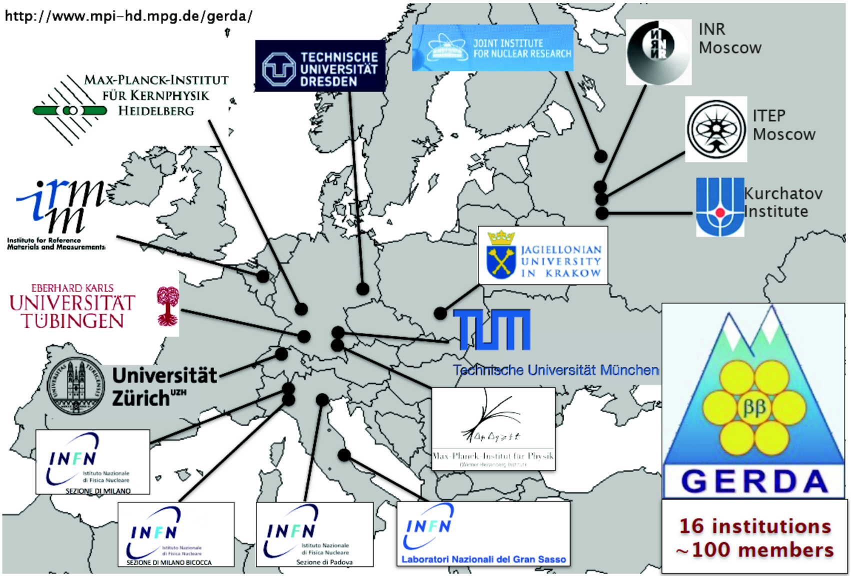
$T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}$yr

Phase II

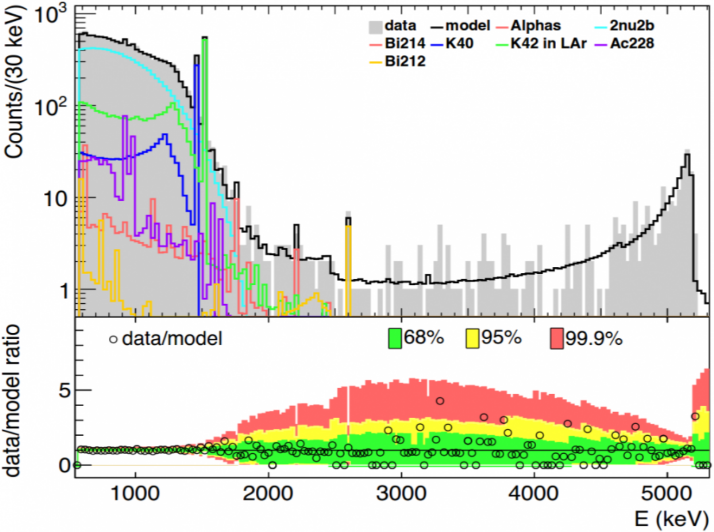
- Doubled mass of ^{76}Ge
- Reduced BI
- New read-out and LAr veto
- Aim exposure of 100 kg·yr
- BI below 10^{-3} cts/(keV·kg·yr)
- Soon: Unlinding results!

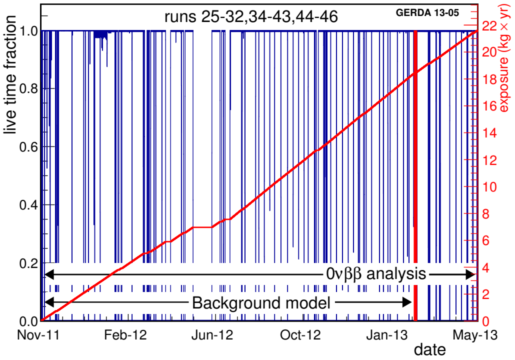


Thank you for your attention!



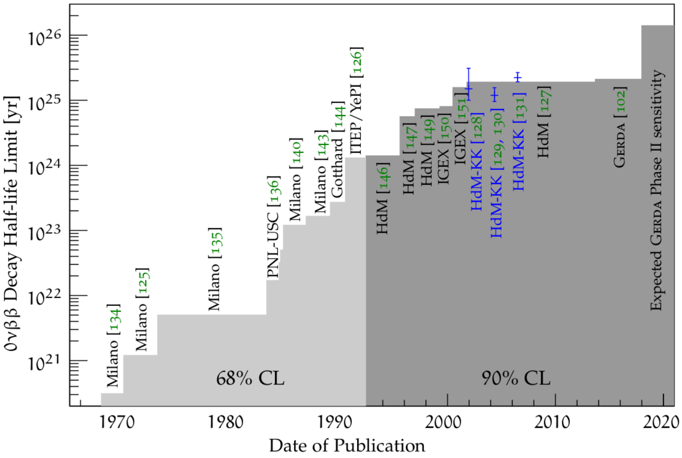
Backup: GERDA Phase II. BEGe background





- Spikes: (Bi)-weekly calibration runs
- Flat parts: BEGe's insertion (June 2012), maintenance operations
- Data set for background model: Nov 2011 - March 2013
- Data set for $0\nu\beta\beta$ decay analysis: Nov 2011 - May 2013

Backup: Limits on $0\nu\beta\beta$ half-life for ^{76}Ge.



The limits up to 1992 correspond to 68% CL, the more recent ones to 90% CL. The three HdM-KK claims are shown with blue error bars.

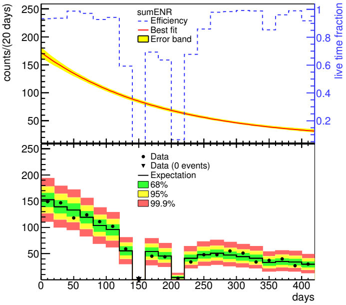
Backup: Blinding of the Region of Interest

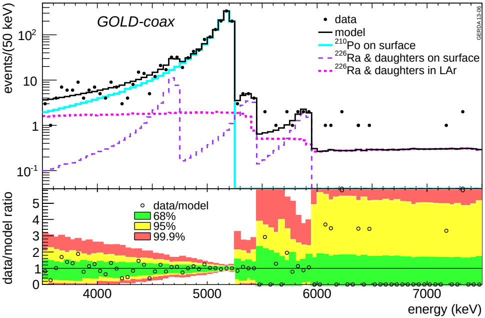
Energy and pulses of events in the $Q_{\beta\beta} \pm 100$keV region automatically hidden

Tasks to be fulfilled before the unblinding

- Reach a big enough exposure
- Have a good enough background model
- Be able to predict a reliable BI at $Q_{\beta\beta}$
- Fix the data selection and the partition
- Fix the data processing procedure (quality cuts, calibration, ...)
- Fix (and publish) the PSD methods and cuts
- Fix the statistical analysis

Backup:The Background Model at High Energy





- Duty-factor corrected time distribution of events in the 3.5-5.3 MeV compatible with ^{210}Po half-life ($T_{1/2} = 138$ d)
- Contribution from ^{226}Ra and daughters also visible
- α emitter mostly located on p^+ surface (also confirmed by PSD)
- α events account for $\sim 10\%$ of the BI at $Q_{\beta\beta}$ for coaxial detectors and $\sim 5\%$ for BEGe's.