The GERDA experiment on the $0\nu\beta\beta$ decay

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Outline

- Introduction
- the GERDA experiment: construction and status
- background measurements in GERDA
- conclusions

Neutrino Properties

Oscillation experiments $\rightarrow$ neutrino mass $\neq 0$

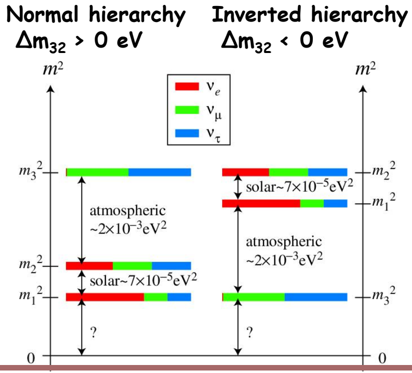
- $m_2^2 - m_1^2 = \Delta m_\odot^2$
- $|m_2^2 - m_3^2| = \Delta m_{atm}^2$

- $\theta_{12} = \theta_\odot$ and $\theta_{23} = \theta_{atm}$

and first measurements on $\theta_{13} \neq 0$

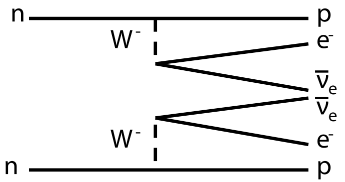
Still Missing

- Nature of the neutrino (Majorana or Dirac)
- Absolute mass scale
- Mass hierarchy
- Sterile neutrinos?
- CP violating phases

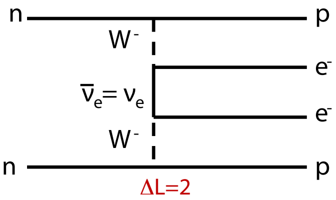


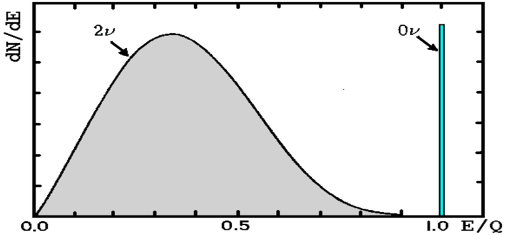
Search for $0\nu\beta\beta$ *decay*

Neutrino accompanied Double-Beta Decay:



Neutrinoless Double-Beta Decay:

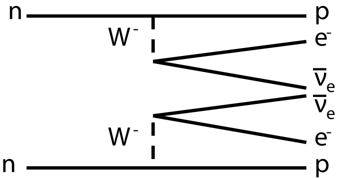




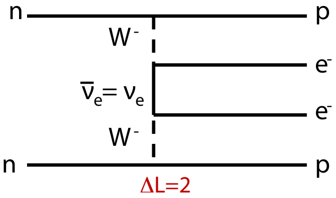
Signature: Sharp peak at Q-value of the decay (2039 keV for ^{76}Ge)

Search for $0\nu\beta\beta decay$

Neutrino accompanied Double-Beta Decay:



Neutrinoless Double-Beta Decay:



If neutrino-less double beta-decay is observed:

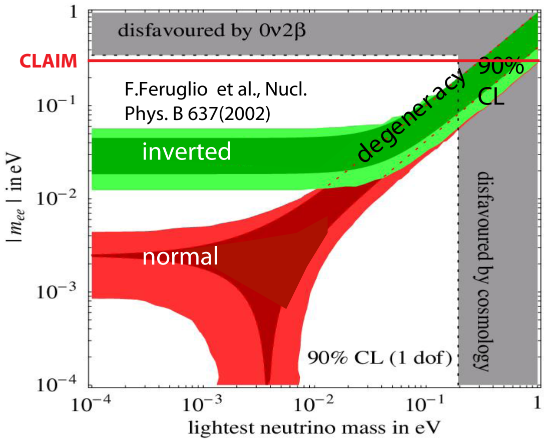
- neutrino is a Majorana particle
- information on absolute mass scale

$$1/\tau = G(Q,Z) \; |M_{nucl}|^2 \; \langle m_{ee} \rangle^2$$

0νββ Decay rate	Phase space factor	Matrix element	Effective Majorana Neutrino mass

$$\langle m_{ee} \rangle = |\sum_i |U_{ei}|^2 e^{i\beta_i} m_i|$$

Search for $0\nu\beta\beta$ *decay*



- Part of Heidelberg-Moscow
- 5 HPGe, 72 (kg y) exposure
- One claim: $T^{0\nu}_{1/2} = 0.69 - 4.18 \cdot 10^{25}$ y
- Several limits given
- Other exp.: EXO, Kamland-Zen, CUORE, MAJORANA, NEXT

The experimental challenge

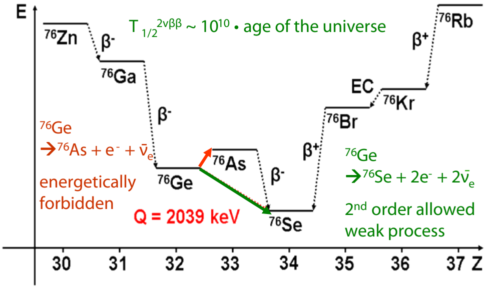
... about 30 isotopes available, but:

$$\text{sensitivity on } T_{1/2} \propto \epsilon \cdot A \cdot \sqrt{\frac{M \cdot T}{b \cdot \Delta E}}$$

ϵ	detection efficiency	$\sim$ 85% if detector=source
A	isotopic abundance	high natural i.a. or enrichment!
M	active target mass	increase mass
T	measuring time	
b	background rate (cts/(keV kg y))	minimize & select radio-pure material
ΔE	energy resolution	use high resolution spectroscopy

Experimental approach: improve exposure (M·T) and resolution, reduce background.

^{76}Ge



Advantages

ultra-pure material

$\Delta E \approx 3$ keV at 2 MeV

high detection efficiency

can be enriched

Disadvantages

A=7.6 %, need enrichment

$Q_{\beta\beta} = 2039$ keV,

background from ^{232}Th

small phase space factor

The GERmanium Detector Array

Challenges

- low rate: 0-10 cts/yr (Phase I)
- expensive detectors, limited time
- background: cosmic muons, “dirty” materials, activation, environmental radioactivity

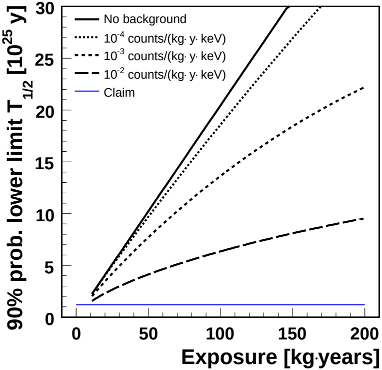
Solution: background reduction

- Naked Ge-diodes enriched to 86% shielded by low-Z materials
- Source = detector, resolution $\approx$ 0.1%
- LNGS: 3500 m.w.e. $\rightarrow$ muons flux red. by $\approx 10^6$
- Pulse shape analysis

The GERmanium Detector Array

Phase I:

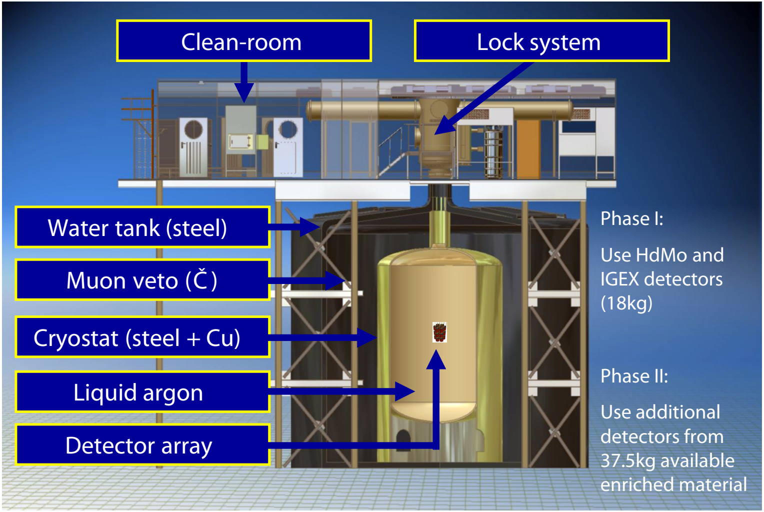
- operate existing HP^{76}Ge detectors from HdM and IGEX + ^{nat}Ge diodes
- for BI of 10^{-2} cts/(keV kg y) and exposure of $\sim$ 15 kg y $\rightarrow$ check claim within 1 y data taking



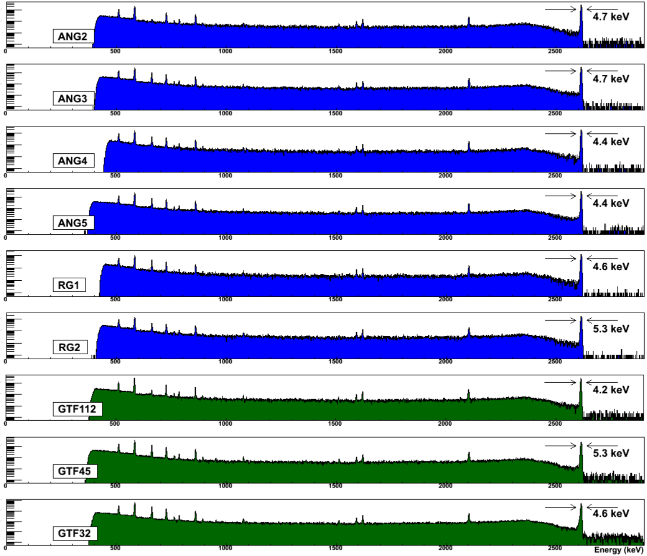
Phase II:

- operate additional new ^{76}Ge detectors for a total of 40 kg
- reach background of 10^{-3} cts/(keV kg y)
- exposure of $\sim$ 100 kg y $\rightarrow$ ${T_{1/2}}^{0\nu} \geq 1.35 \cdot 10^{26}$ y (90% C.L.)

The GERmanium Detector Array

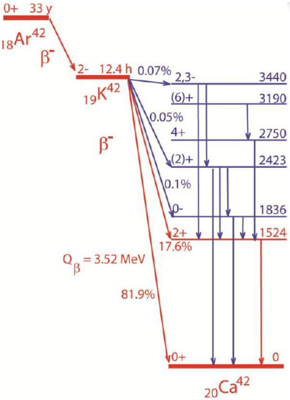


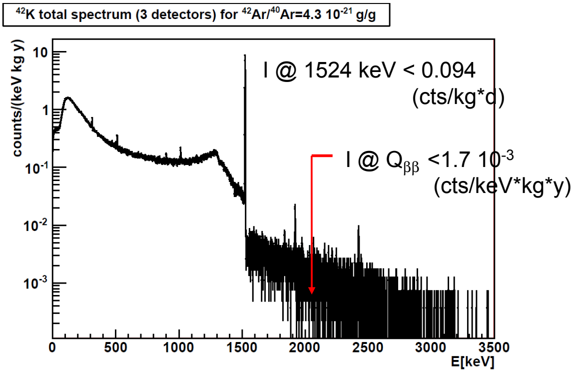
Energy calibration with ^{228}Th source



Commissioning runs : the ^{42}Ar

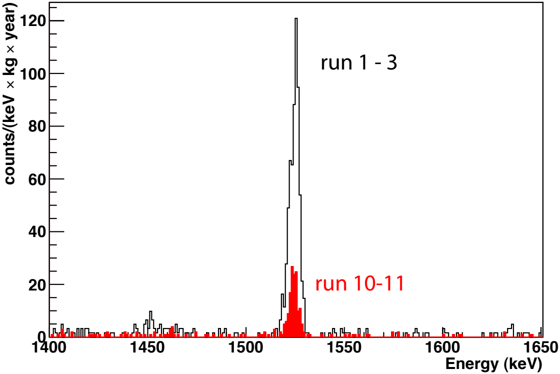
- production: ^{40}Ar(α,2p)^{42}Ar reaction in atmosphere and fall-out from atmospheric nuclear explosion

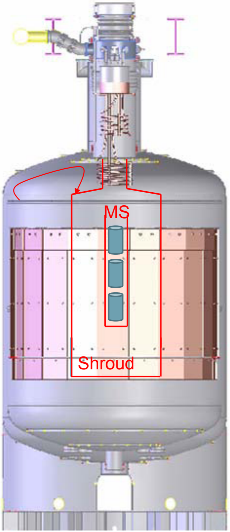




See HK 40.4

GERDA background with mini-shroud



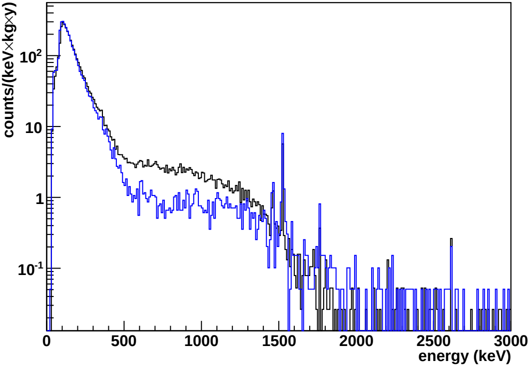


Observed : $I_{\mathrm{measured}} > 10\ I_{\mathrm{expected}}$

Tested different electric field configuration by biasing shroud and mini-shroud

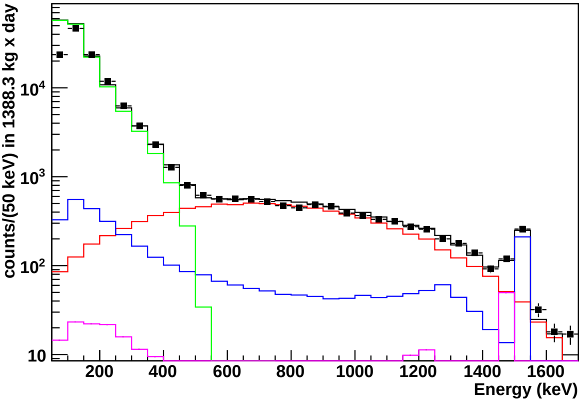
Current status

- phase I started in November 2011
- 8 ^{enr}Ge detectors (2 not considered in the analysis): 14.6 kg
- 3 ^{nat}Ge detectors: 7.6 kg
- since January 2012: blinding at ($Q_{\beta\beta} \pm 20$) keV
- unblinding when sufficient exposure is reached



^{nat}Ge, 2.0 kg y ^{enr}Ge, 3.8 kg y

Current results: $2\nu\beta\beta$ spectrum



exp. 39Ar spec., 1.01 Bq

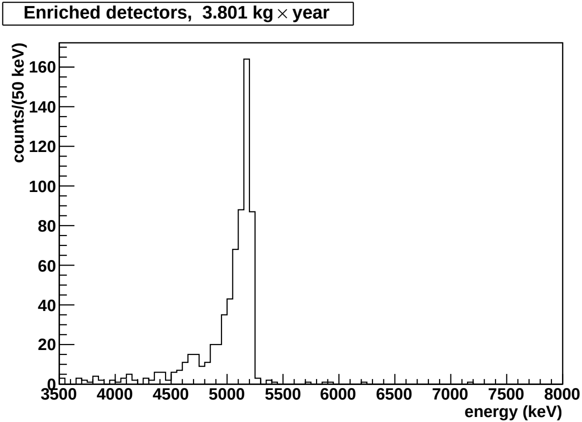
exp. $2\nu2\beta$ spec., $1.74 \cdot 10^{21}$ y

42K spec., uniform, norm. on peak

sim. 40K spec., holders

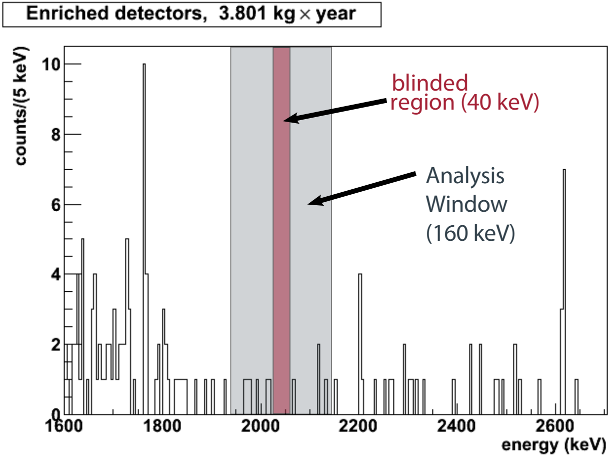
3.8 kg y, enr. Ge, 85% active vol.

Current results: alpha contribution



explained by ^{210}Pb contamination on the bore-hole, mostly from one detector

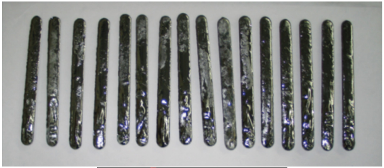
Current results: background index

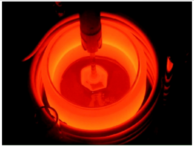


current background index: $0.017^{+0.009}_{-0.005}$ cts/(keV kg y)

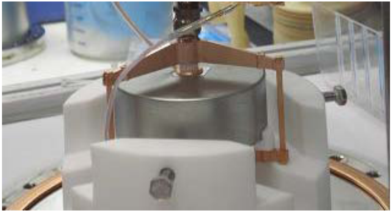
Ge-Procurement and Detector fabrication for Phase II

- 2009: 37.5 kg GeO2 produced by ECP, Zelengorsk, Russia
- 2010: Reduction and zone refinement, PPM Metals GmbH, Rammelsberg, Germany
- 2011: Transport to Oak Ridge, United States
- 2011-12: Crystal pulling and cutting, Canberra, Oak Ridge
- 2012: Diode fabrication & testing, Canberra, Geel, Belgium. First detectors with 1.7 keV@1.3MeV
- complete production chain tested with depleted Ge



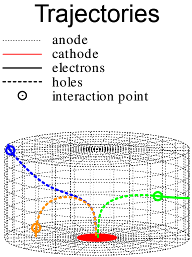


Phase II detectors

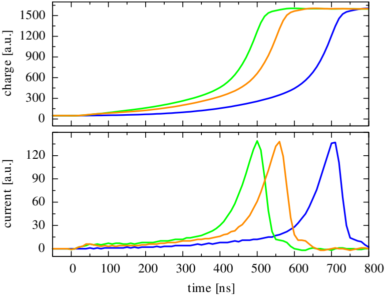


Broad-Energy GErmanium (BEGe) detector

- Low capacitance → high energy resolution: 1.6 keV @ 1.332 MeV
- good pulse shape discrimination:

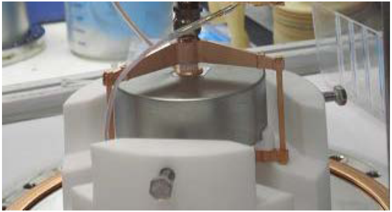


Signal for different trajectories



M. Agostini et al., JINST 6P03005 (2011)

Phase II detectors



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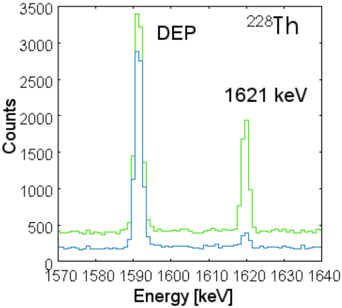

D. Budjas et al., JINST 4P10007 (2009)

- PSA accepting 90% of ^{208}Tl DEP (SSE → $0\nu\beta\beta$-like)
- about 10% survival of the ^{212}Bi γ-line (mainly MSE)

Conclusions

- The $0\nu\beta\beta$ decay can prove physics beyond the SM
- GERDA tries to determine $T_{1/2}$ of ^{76}Ge via an innovative approach
- The current BI of $1.7 \cdot 10^{-2}$ cts/(keV kg y) is very promising
- The crucial / blinded phase of data taking has begun, 1/4 of desired exposure (Phase I) has been reached
- Production of next-generation Ge detectors in under way.
- First BEGes tested with excellent resolution (1.7 keV1.3 MeV)
- development of LAr readout to further suppress background
  $\rightarrow$ See HK 18.2, HK 40.5 & HK 40.6