The GERDA search for neutrinoless double beta decay

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Neutrinoless Double Beta Decay

Effective Majorana Neutrino Mass

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

SM allowed and observed in many isotopes.

$0\nu\beta\beta$ $(A, Z) \rightarrow (A, Z+2) + 2e^-$

$\Delta L = 2$

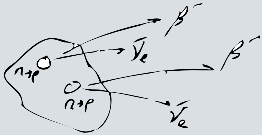
Half-life

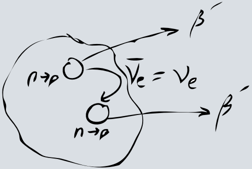
$$(\mathrm{T}^{0\nu}_{1/2})^{-1} = \mathrm{G}^{0\nu} \cdot |\mathrm{M}^{0\nu}|^2 \cdot \langle m_{\beta\beta} \rangle^2$$

$\mathrm{G}^{0\nu}$: Phase space integral

$\mathrm{M}^{0\nu}$: Nuclear matrix elements

$\langle m_{\beta\beta} \rangle^2 = |\sum_i U^2_{ei} e^{\alpha_i} m_i|^2$





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

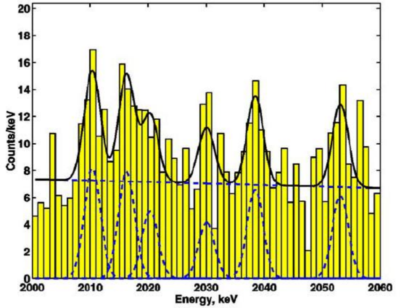
Experimental approach: improve exposure (M·T) and resolution, reduce background.

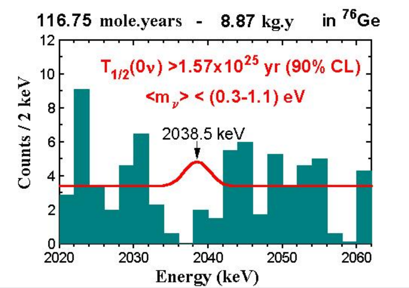
Previous ^{76}Ge Experiments

	HdMo	IGEX		
Location	LNGS	Homestake	Baksan	Canfranc
Overburden [m.w.e.]	3800	4000	660	2450
Exposure [kg · yr]		2.4	2.5	4.0
	71.1		8.9	
Bg [counts/kg·keV·yr]	0.11		0.17	
$T_{1/2}$ limit (90% CL)[yr]	1.9×10^{25}		1.57×10^{25}	

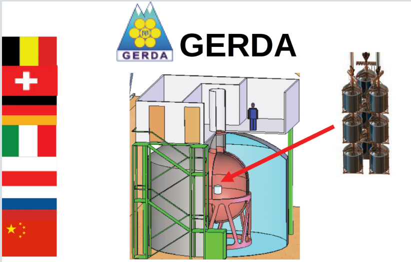
"Evidence for $0\nu\beta\beta$" $0.69 - 4.18 \times 10^{25}$ [yr] 3σ

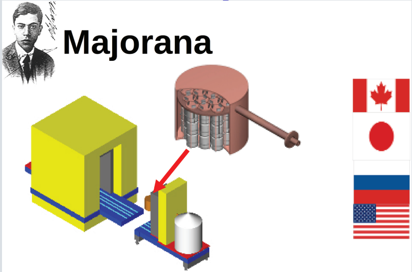
H.V. Klapdor-Kleingrothaus, *et. al*, Phys. Lett. B 586 (2004) 198-212





Two New ^{76}Ge Projects





- 'Bare' ^{enr}Ge array in liquid argon
- Shield: high-purity liquid argon/H_2O
- Phase I: 18 kg (HdMo/IGEX)/15 kg nat.
- Phase II: add $\sim$ 20 kg new enr. detectors total $\sim$ 40 kg

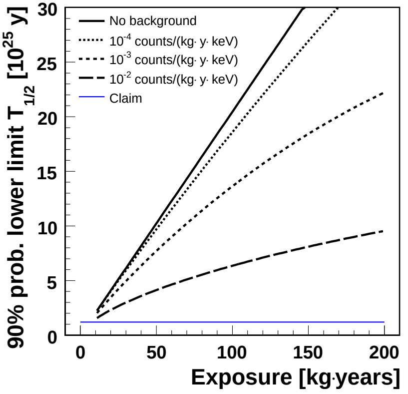
- Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper/lead
- Initial phase: R&D demonstrator module Total $\sim$ 60 kg (30 kg enr.)

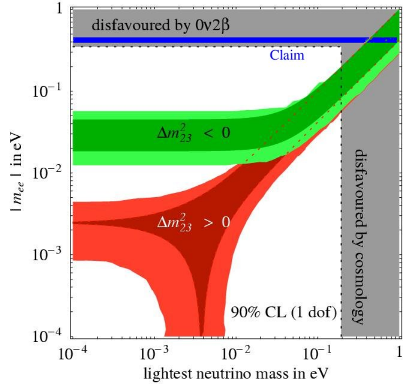
Physics goals: degenerate mass range
Technology: study of bgds. and exp. techniques

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for O(1 ton) exp. (inv. Hierarchy) selecting the best technologies tested in GERDA and Majorana

GERDA Physics Goal

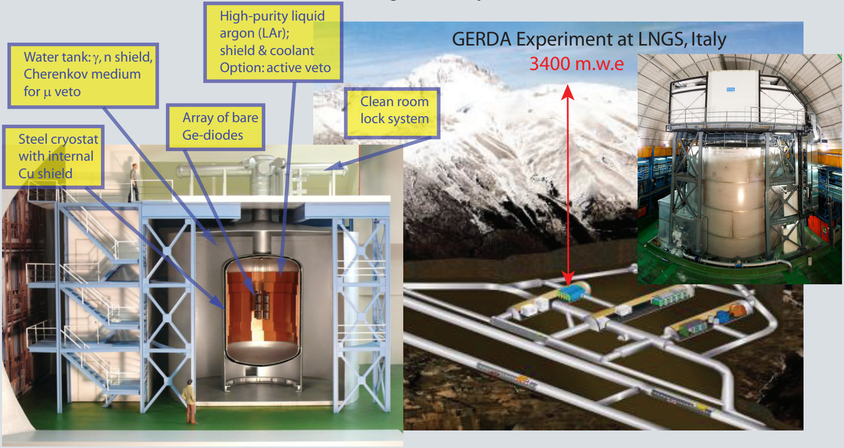
Phase	I	II	Ton Scale
Exposure [kg·yr]	15	100	$>$1000
Bg [counts/kg·keV·yr]	10^{-2}	10^{-3}	10^{-4}
Upper limit $m_{\beta\beta}$[eV]	0.23-0.39	0.09-0.15	$\sim$0.05
A. Smolnikov, P. Grabmayr			Merge
PRC 81 028502(2010)			with Majorana





Background Reduction

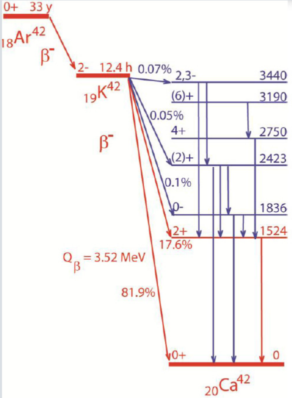
Deep underground site for suppression of cosmic ray muons
Graded shielding against ambient radiation
Rigorous material selection
Signal Analysis



Suppression of μ-flux $> 10^6$

Commissioning runs

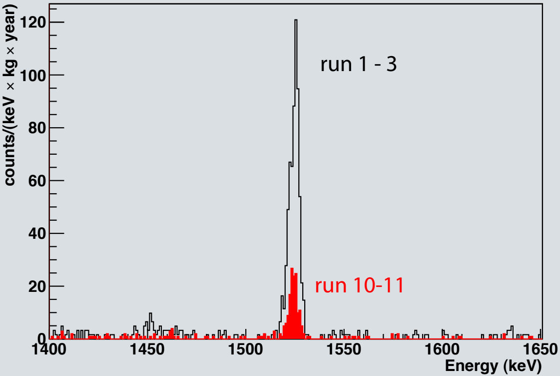
- From 16-Jul-2010 to 12-Apr-2011
- Purpose: to find running configuration with minimum background
- Identified single line from ^{42}Ar
- Produced by ^{40}Ar(α,2p)^{42}Ar cosmogenic reaction in upper atmosphere and fall-out from atmospheric nuclear weapons tests

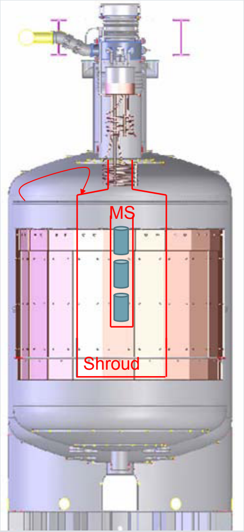


I @ 1524 keV < 0.094 (cts/kg*d)

I @ $Q_{\beta\beta}$ <1.7 10^{-3} (cts/keV*kg*y)

GERDA background with mini-shroud



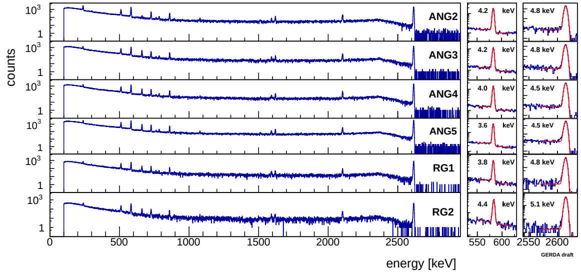


Observed : $I_{measured} > 10\ I_{expected}$
Tested different electric field configuration by biasing shroud and mini-shroud

Current status

- Phase-I started on 1 Nov. 2011
- 6 ^{enr}Ge detectors: 14.6 kg
- 3 ^{nat}Ge detectors: 7.6 kg removed on 23 May 2012
- Resolution $<$ 5.1 keV at 2.6 MeV
- duty cycle 92.6% without run 31
- overall duty cycle 78.3%
- Since January 2012: blinding at ($Q_{\beta\beta} \pm 20$) keV
- Unblinding when sufficient exposure is reached

Calibration run with thorium source



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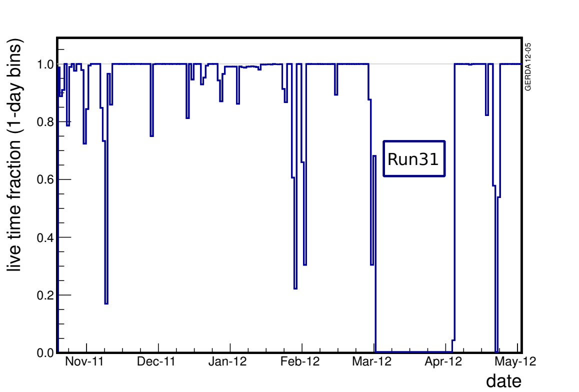

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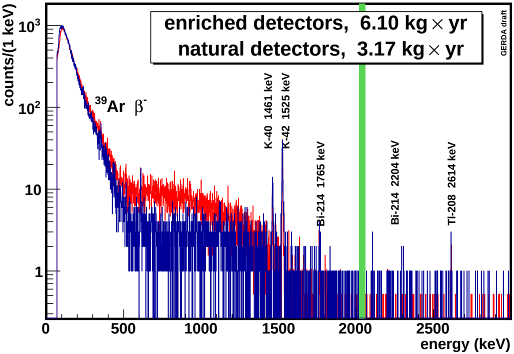
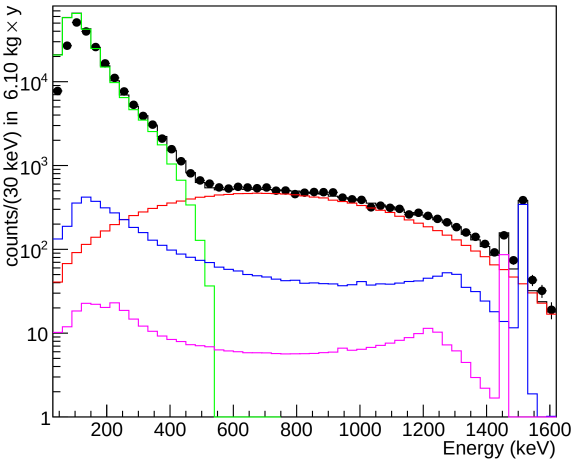


Current results: $2\nu\beta\beta$ spectrum

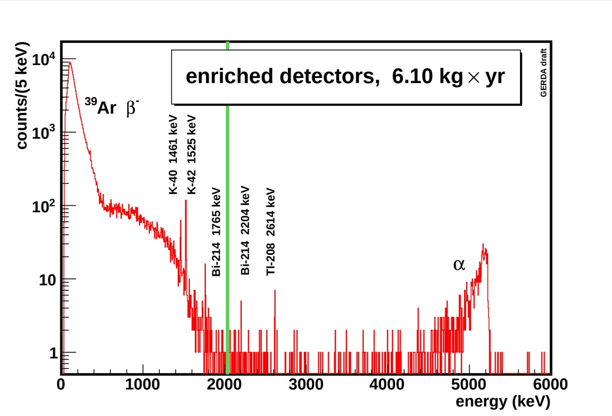


Points: dataset 6.10 kg·yr
Line: sum of the following

39Ar spec. 1.01 Bq/kg
from NIM A 574 (2007) 83
$2\nu\beta\beta$ spec.
Best Fit
42K spec. uniform dist.
Best Fit
40K spec. on holders
Best Fit

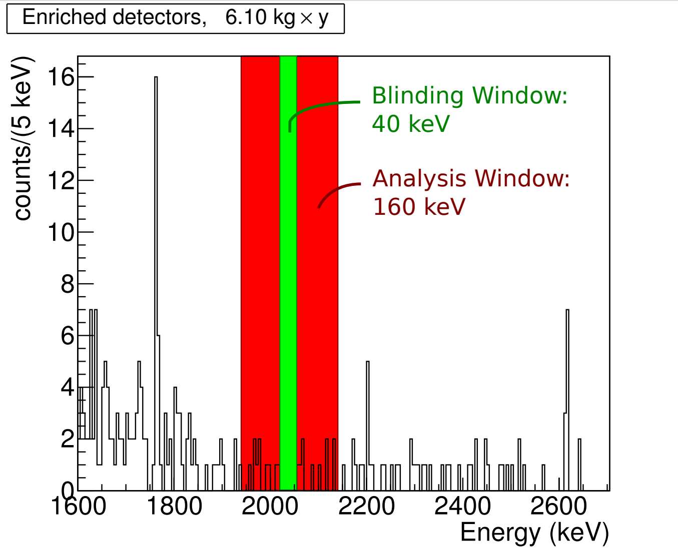
Expect an independant measurement of $2\nu\beta\beta$ soon!

Current results: alpha contribution



- Alpha candidate events occur with varying frequency for each detector suggesting a surface contamination mostly on two detectors
- Monte Carlo study suggests ^{210}Po α-decays inside the bore hole dead layer of 500 nm

Current results: background index



current background index: $0.0203^{+0.0057}_{-0.0043}$ cts/(keV kg y)
(68% Coverage)

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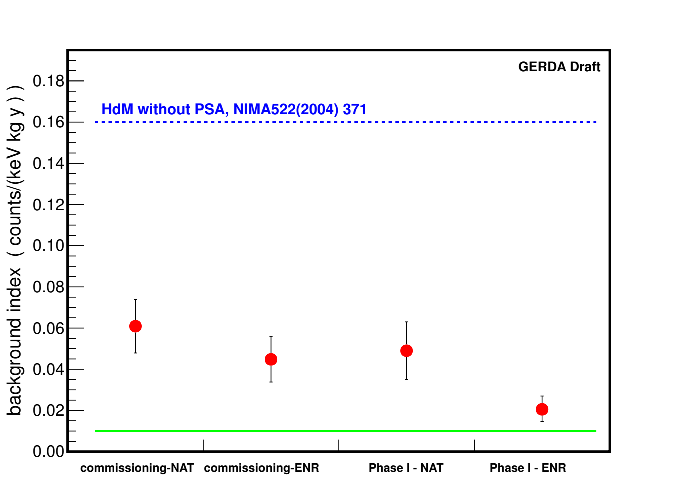

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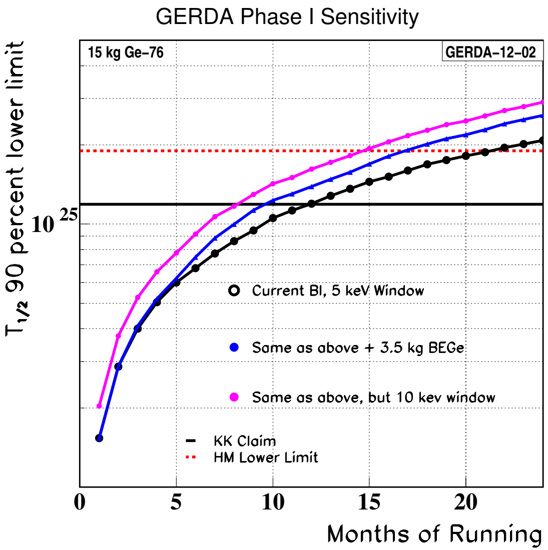
Projected sensitivity



currently at 5 months of running time

Phase II Detector Production

- Purchase Enriched $^{76}GeO_2$: ECP Zelenogorsk, RU

- Metal Reduction and Zone Refinement: Langelsheim, DE
  08 Mar 2010 to 30 Apr 2010
- Crystal Pulling: Oak Ridge, TN, USA: Since 17 Oct 2011
- BEGe Detector Diode Production: Olen, BE: Since 19 Jan 2012

Phase II Detector Production

- Purchase Enriched $^{76}GeO_2$: ECP Zelenogorsk, RU
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35.5 kg Enriched HPGe 6N material

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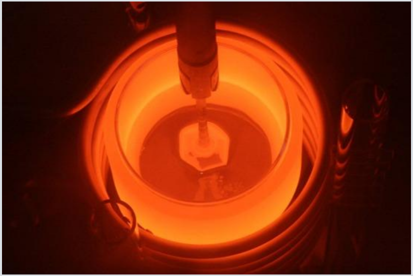

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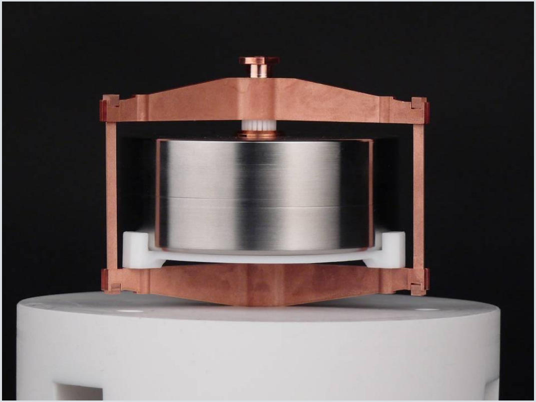


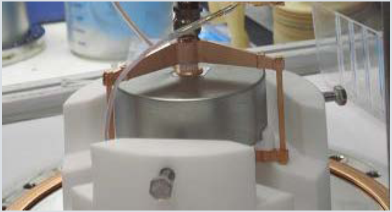
GERDA Phase-II

- Detector Production Status
  - First of two batches of crystals has been processed: 7 diodes
  - Resolution $\sim$ 1.7 keV 1.3 MeV in vacuum cryostat
  - 5 diodes being prepared for insertion in phase-I
- New 3-string lock supporting 24 BEGes in each arm
  - Strict limits on radiopurity
  - Move detectors further from steel support chain
  - New low-mass two component front end for preamplifier
- Intelligent design
  - Improved Pulse Shape Analysis capability with BEGe detectors to reject multi-site events
  - Utilization of the scintillation properties of LAr to veto compton and surface background events

Conclusions

- GERDA aims to determine $T_{1/2}$ of ^{76}Ge via an innovative approach, operating germanium detectors bare in liquid argon
- Phase-I began on 1 Nov. 2011 and has been running since with an overall duty cycle of 78.3%
- The current BI of $2.0 \cdot 10^{-2}$ cts/(keV kg y) is a significant improvement over previous ^{76}Ge searches
- We will reach our designed sensitivity for Phase-I in a maximum of 15 months
- Since it is planned to install Phase-II detectors in Phase-I, we will probably reach this goal even sooner.
- Production of next-generation detectors is in an advanced phase
- First BEGes tested in vacuum with excellent resolution (1.7 keV 1.3 MeV)
- Improved PSA and a LAr veto will further supress backgrounds to reach the goals of Phase-II GERDA

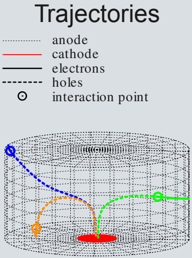
Phase II detectors

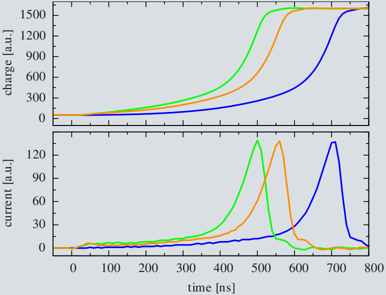


Broad-Energy GErmanium (BEGe) detector

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

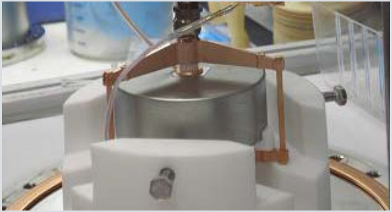
Signal for different trajectories





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

Phase II detectors



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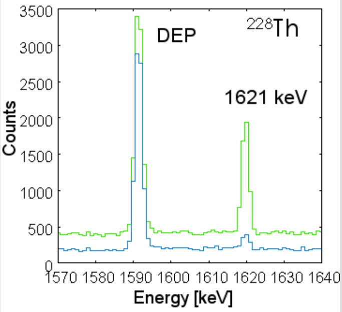

D. Budjas et al., JINST 4P10007 (2009)

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