The GERDA experiment for the search of neutrinoless double beta decay: status and perspectives

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Outline

Neutrinoless double beta decay

The GERDA experiment

GERDA Phase I: status and first results

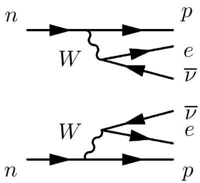
GERDA Phase II: preparation and plans

Double beta decays

Second order nuclear transitions → decay of two neutrons into two protons:

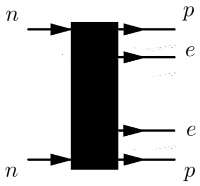
2-neutrino final state ($2\nu\beta\beta$):

- $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$
- allowed in the Standard Model
- measured in several isotopes
- $T^{2\nu}_{1/2}$ in the range $10^{19} - 10^{24}$ yr



0-neutrino final state ($0\nu\beta\beta$):

- $(A, Z) \rightarrow (A, Z+2) + 2e^-$
- lepton number violation ($\Delta L = 2$)
- physics beyond the Standard Model (e.g. right-handed weak currents, super-symmetric particles. . .)
- ν Majorana mass component (Schechter-Valle theorem)
- $T^{0\nu}_{1/2}$ limits in the range $10^{21} - 10^{25}$ yr
- one unconfirmed claim (subgroup of HdM experiment)



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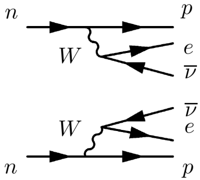

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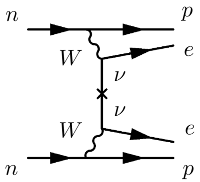
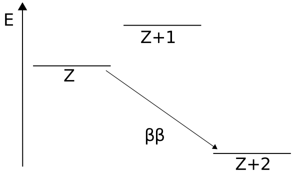
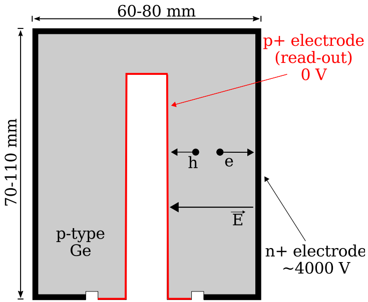


$(T^{0\nu}_{1/2})^{-1} \propto \langle m_{\beta\beta} \rangle^2$

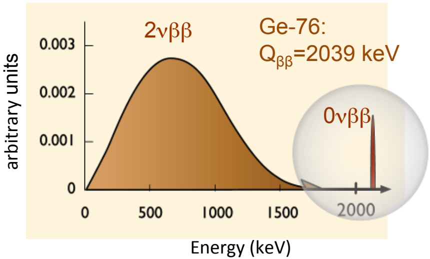
Experimental aspects of $0\nu\beta\beta$ search in Ge-76

- even-even nuclide for which β decay is energetically forbidden
- HPGe detectors from Ge material enriched in ^{76}Ge ($\sim$87%)
- detectors well established technology
- optimal spectroscopy performance:
  - long-term stability
  - $\Delta E \approx 0.1\%$ at $Q_{\beta\beta}$
  - radio purity



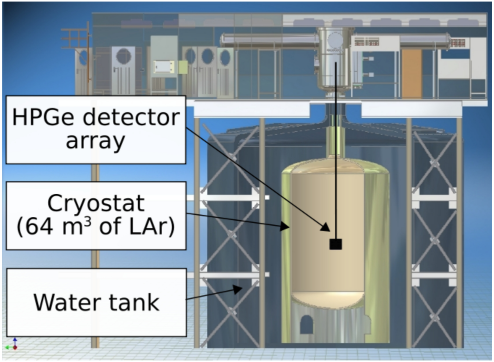


Calorimeter detectors:
- source=detector
- high detection efficiency
- peak at Q-value ($Q_{\beta\beta}$)



Concept and goals

- Bare Ge detectors in liquid Argon (LAr)
- Shield: high-purity LAr/H_2O
- Radio-pure material selection
- deep underground (LNGS, 3800 m.w.e.)



	^{76}Ge detectors	target mass [kg]	background at $Q_{\beta\beta}$ [cts/(keV· kg· yr)]	sensitivity goal
Phase I (Nov 11 - Spring 13)	8 coaxial	17.7 kg	10^{-2}	scrutinize the claim $T_{1/2}^{0\nu} \sim 1.2 \cdot 10^{25}$ yr (Phys.Lett. **B586** 2004)
Phase II (starting in 2013)	8 coaxial 30 BEGe	17.7 kg 20 kg	$\lesssim 10^{-3}$	$T_{1/2}^{0\nu} > 10^{26}$ yr

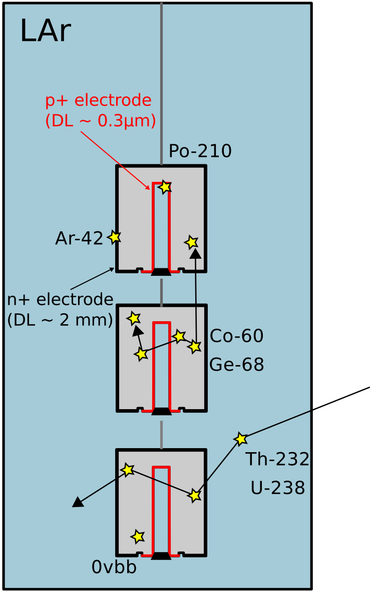
Backgrounds and mitigation techniques

Background sources:

- natural radioactivity (^{232}Th and ^{238}U chains):
  - ▷ γ-rays (e.g. ^{208}Tl, ^{214}Bi)
  - ▷ α-emitting isotopes from surface contamination (e.g. ^{210}Po) or ^{222}Rn in LAr
- cosmogenic isotopes in Ge decaying inside the detectors (^{68}Ge, ^{60}Co)
- unstable Ar isotopes (^{39}Ar,^{42}Ar)

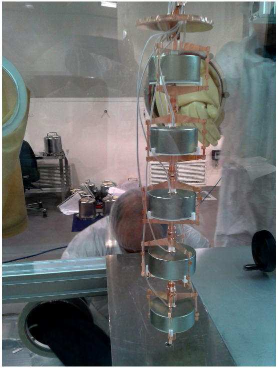
Mitigation strategy:

- detector anti-coincidence (already used in Phase I)
- time-coincidence (Bi-Po or Ge-68)
- pulse shape analysis (in future)
- LAr-scintillation (only Phase II)



Detector array assembly

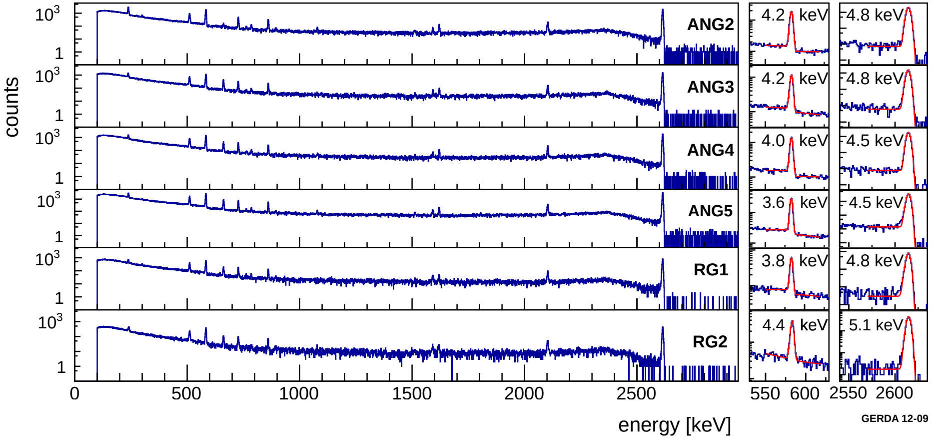




- 3 + 1 strings
- 8 ^{enr}Ge coaxial detectors (2 not considered in the analysis)
- 3 ^{nat}Ge coaxial detectors
- 5 ^{enr}Ge BEGe detectors (R&D for Phase II)

^{enr}Ge mass for physics analysis: 14.6 kg (coaxial) + 3.6 kg (BEGe)

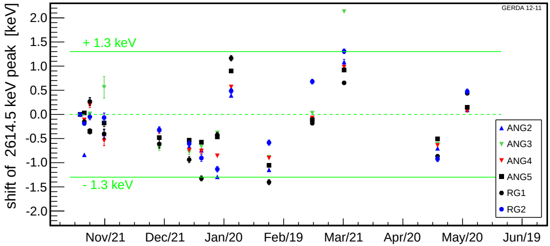
Detector calibration (Th-228)

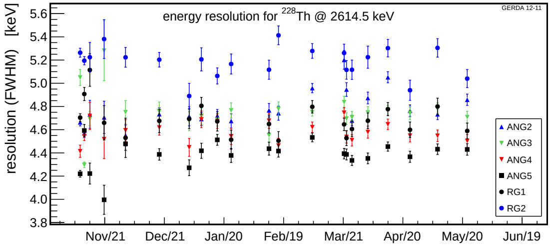


Energy resolution at $Q_{\beta\beta}$ (FWHM, mass weighted average):

- ∼ 4.5 keV for coaxials
- ∼ 3 keV for BEGes

Detector stability

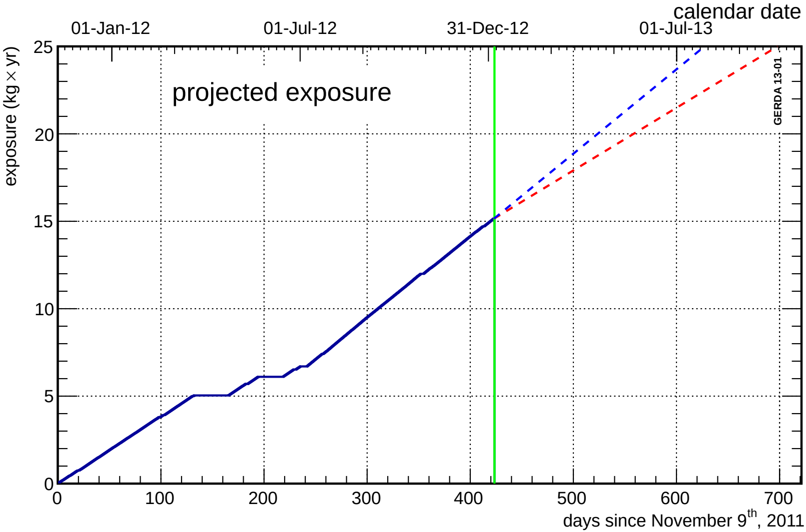




- calibration every one/two weeks
- energy shift between successive calibration runs usually $\lesssim 1\ keV$
- energy resolution stable

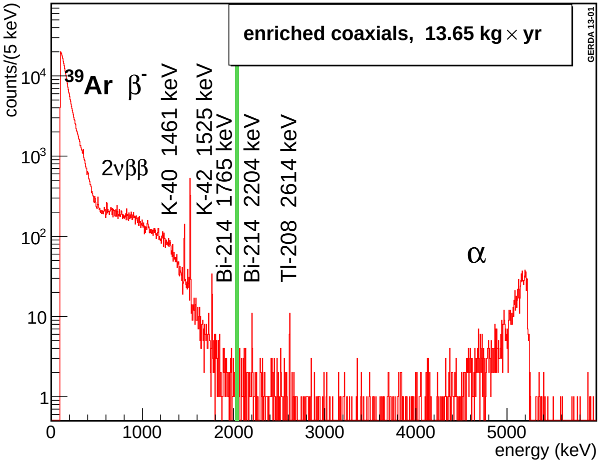
[EPJ C 73 (2012)]

Integrated exposure



15 kg·yr in Jan 2013 —> 20 kg·yr (Phase I exposure goal) already reached

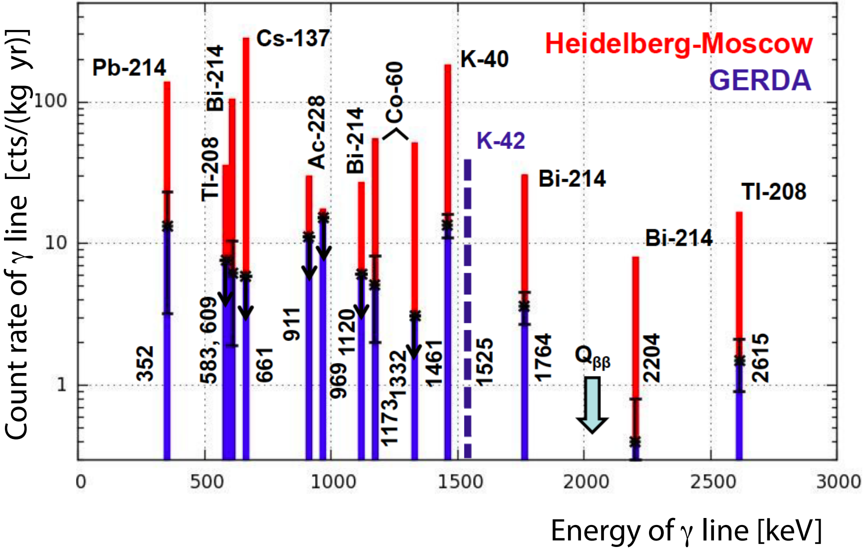
Main structures in the energy spectrum



- ^{39}Ar (up to 565 keV)
- $2\nu\beta\beta$(dominant up to 1400 keV)
- ^{40}K (γ at 1461 keV)
- ^{42}K (γ at 1525 keV)
- ^{214}Bi (γ at 1765 and 2204 keV)
- ^{208}Tl (γ at 2615 keV)
- ^{210}Po (α peak at 5.3 MeV)
- ^{226}Ra chain (cts above 5.3 MeV)

Blinded analysis —> events at $Q_{\beta\beta}\pm 20$ keV are not available for analysis

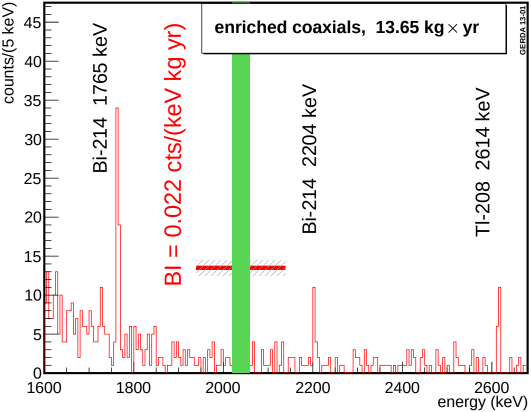
Gamma-line intensities



Background index in the $Q_{\beta\beta}$ region

Average background index values in $Q_{\beta\beta}\pm100$ keV (excluding central 40 keV):

- $2.2^{+0.3}_{-0.3}\cdot10^{-2}$ cts/(keV· kg· yr), ^{enr}Ge coaxials, 13.6 kg·yr
- $1.7^{+0.3}_{-0.3}\cdot10^{-2}$ cts/(keV· kg· yr), ^{enr}Ge coaxials, 12.3 kg·yr (w/o run 34/35, 8% exp)
- $4.1^{+1.5}_{-1.2}\cdot10^{-2}$ cts/(keV· kg· yr), ^{enr}Ge BEGe's, 1.5 kg·yr

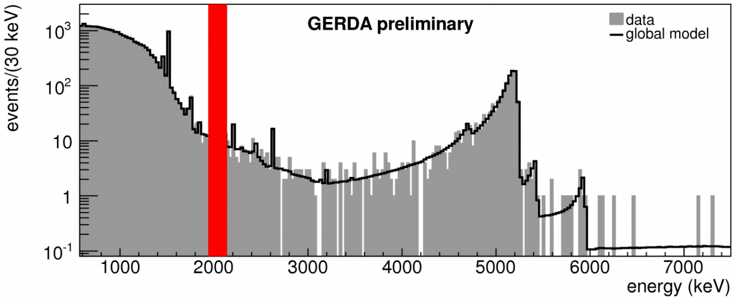


Previous exp (i.e. HdM & IGEX):
BI $\sim$ 0.17 cts/(keV· kg· yr)

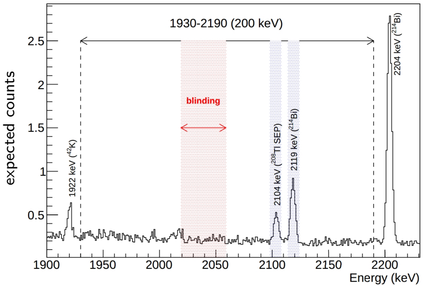
Background contributions at $Q_{\beta\beta}$:

- γ: Tl-208 and Bi-214
- β: K-42 and Bi-214
- α: Po-210, Rn-226 chain

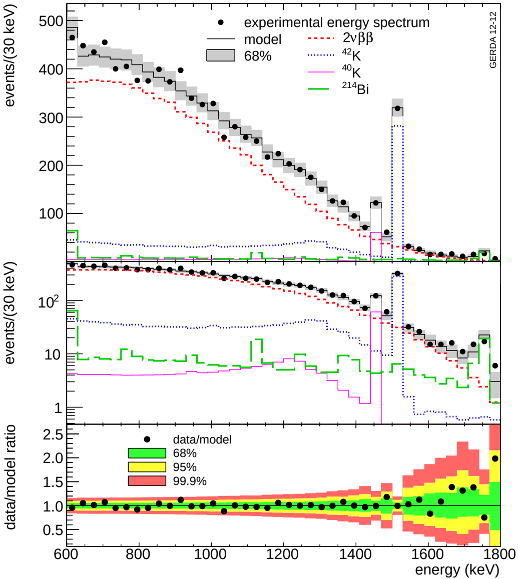
Background model at $Q_{\beta\beta}$ – Preliminary



- binned maximum posterior fit (coax only)
- fit window 570-7500 keV
- p-value of the fit: 0.3
- main contributions considered:
  - $2\nu\beta\beta$
  - K-40
  - K-42
  - Bi-214
  - Th-228
  - α-emitting isotopes



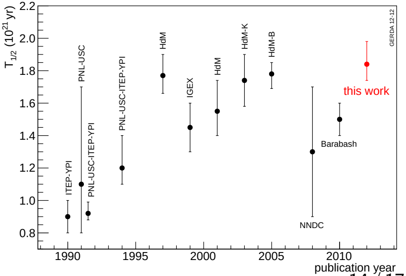
Background model – $2\nu\beta\beta$ half-life



- Binned maximum likelihood (5 kg·yr)
- Nuisance parameters:
  - Active detector masses (6+1)
  - Ge-76 fractions (6)
  - Background contributions (3x6)
- $T_{1/2}^{2\nu}$ common to all detectors
- After marginalizing:

$$T_{1/2}^{2\nu} = (1.84^{+0.09}_{-0.08}\ _{\text{fit}}\ {}^{+0.11}_{-0.06}\ _{\text{syst}}) \cdot 10^{21}$$

[J.Phys.G 40 (2013) 035110]



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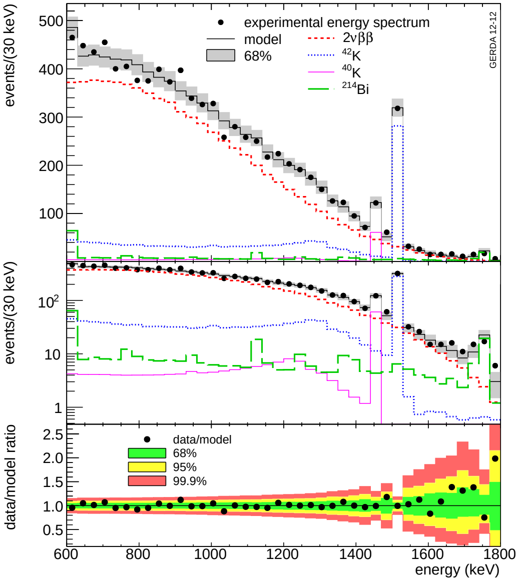

- Binned maximum likelihood (5 kg·yr)
- Nuisance parameters:
  - Active detector masses (6+1)
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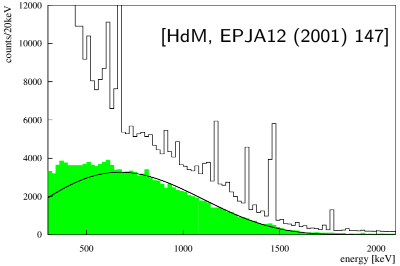


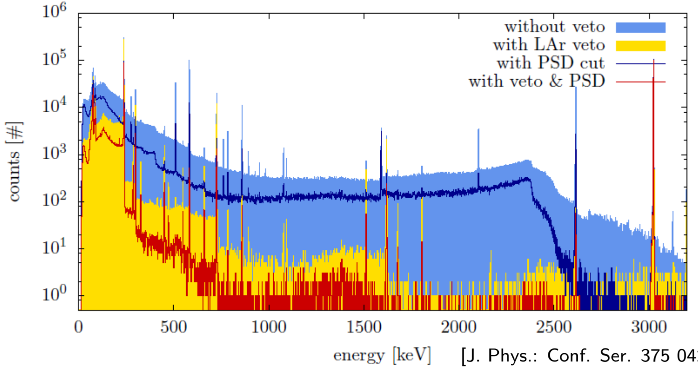
Phase II detectors and liquid argon scintillation

BEGe detectors:

- excellent energy resolution (1.6 keV @ 1.3 MeV)
- enhanced pulse shape discrimination performance
- 30 new ^{enr}Ge BEGe detectors produced (20 kg)

LAr-scintillation (combined design):

- low-background photo-multipliers
- WLS fibers read-out with Si photo-multipliers



[J. Phys.: Conf. Ser. 375 042009]

Pulse shape analysis combined with LAr-scintillation (in LArGe setup): measured suppression factor of $(5.2 \pm 1.3) \cdot 10^3$ at $Q_{\beta\beta}$ for close Th-228

Conclusions

- GERDA Phase I started in Nov 2011
- Data taking ongoing —> collected more than 20 kg·yr of exposure
- Background order of magnitude lower than previous experiments

  $\sim$0.02 cts/(keV· kg· yr) at $Q_{\beta\beta}$

- Measured $2\nu\beta\beta$ half-life with a strong reduction of systematic uncertainties with respect to the previous experiments

  $$T^{2\nu}_{1/2} = (1.84^{+0.09}_{-0.08}\ _{\text{fit}}\ ^{+0.11}_{-0.06}\ _{\text{syst}}) \cdot 10^{21}$$

- Phase I almost complete: data unblinding June! Average expected $0\nu\beta\beta$ sensitivity of:

  $$T^{0\nu}_{1/2} \gtrsim 1.9 \cdot 10^{25}\,\text{yr}$$

- Transition to Phase II in preparation (starting in summer 2013): major upgrade for further reduction of the background to the level of 10^{-3} cts/(keV· kg· yr) at $Q_{\beta\beta}$ (pulse shape analysis with BEGe detectors and LAr instrumentation).