Background free search for neutrinoless double beta decay with GERDA Phase II

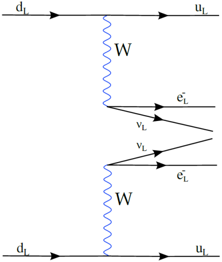
Anne Wegmann for the GERDA collaboration

Max-Planck Institut für Kernphysik

Rencontres de Blois, Blois, 30 May 2017

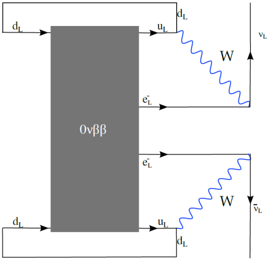
Doube beta decays

$2\nu\beta\beta$:

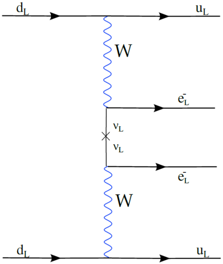


- second order process
- allowed by Standard Model (SM)
- half-life: $T_{1/2}^{2\nu}(^{76}Ge) = (1.926 \pm 0.094)\,10^{21}$ yr
[EPJC 75 (2015) 416]

$0\nu\beta\beta$:



- hypothetical process predicted by several extensions of SM
- $\Delta L = 2$: lepton number violation → BSM (talk by W. Rodejohann)
- ν has Majorana mass component

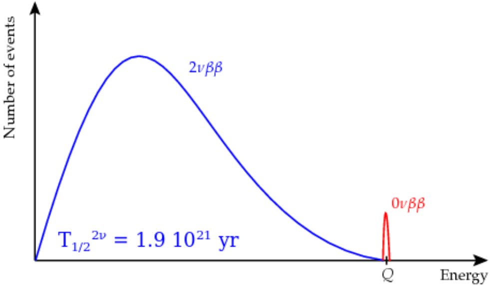


- possible realization: light Majorana neutrino exchange

⇒ access to effective Majorana neutrino mass $m_{\beta\beta}$

Signature and experimental challenges

- measure sum energy of electrons



- observable: $(T^{0\nu}_{1/2})^{-1} \propto N_{0\nu}$
- need to achieve
  1. < 1 background event in ROI
  2. excellent energy resolution

- zero background regime

$$T^{0\nu}_{1/2} \propto M \cdot t$$

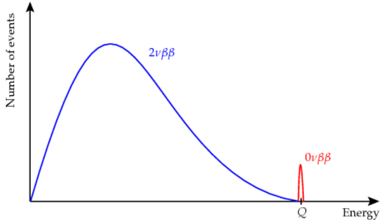
- background, i.e. statistical fluctuation limited scenario

$$T_{1/2} \propto a \cdot \epsilon \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot BI}}$$

ϵ: detection efficiency,
a: abundance of ^{76}Ge
Mt: exposure,
BI: background index,
ΔE: energy resolution in ROI at $Q_{\beta\beta}$

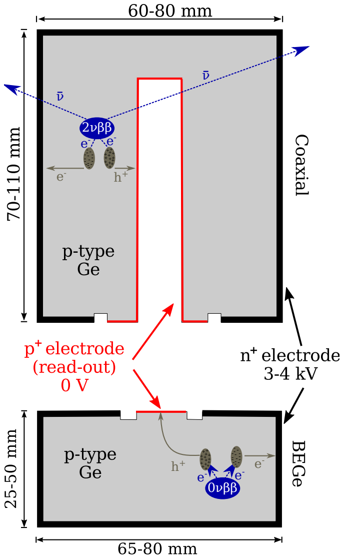
Search for neutrinoless double beta decay of ^{76}Ge

- measure sum energy of electrons



High purity Germanium (HPGe) detectors

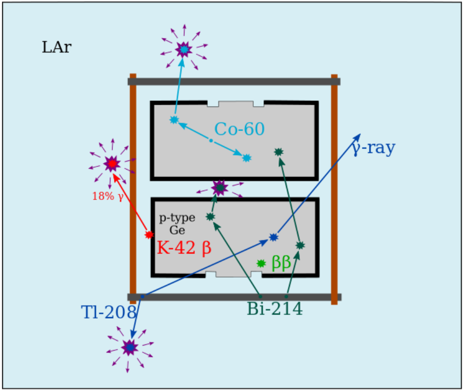
- 3-4 keV FWHM at $Q_{\beta\beta} = 2039\,\mathrm{keV}$ (0.2%)
- isotopically enriched in ^{76}Ge ($\sim$ 87%)
- high detection efficiency of $\beta\beta$-events: source = detector
- no intrinsic background [Astropart.Phys. 91 (2017) 15-21]
- discrimination of signal- from background like events using pulse shape analysis



The GERDA appraoch

- background reduction by
  - ➢ material selection/passive shielding
  - ➢ **active background suppression**

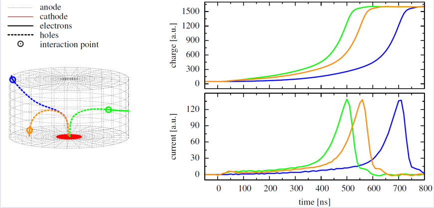
⇒ bare Ge detectors in LAr



Active background suppression

discriminate point-like (SSE) $\beta\beta$ interaction in bulk from background processes by event topology

- **AC**: detector anti-coincidence
- **LAr veto**: scintillation light read-out (Phase II)
- **PSD**: pulse shape discrimination



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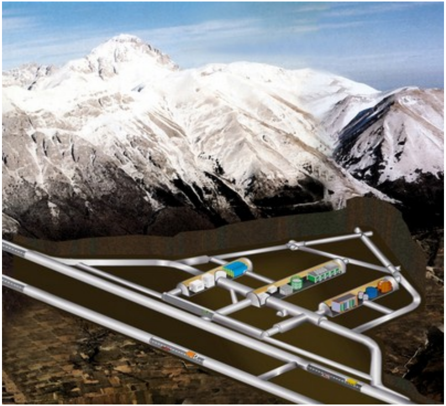
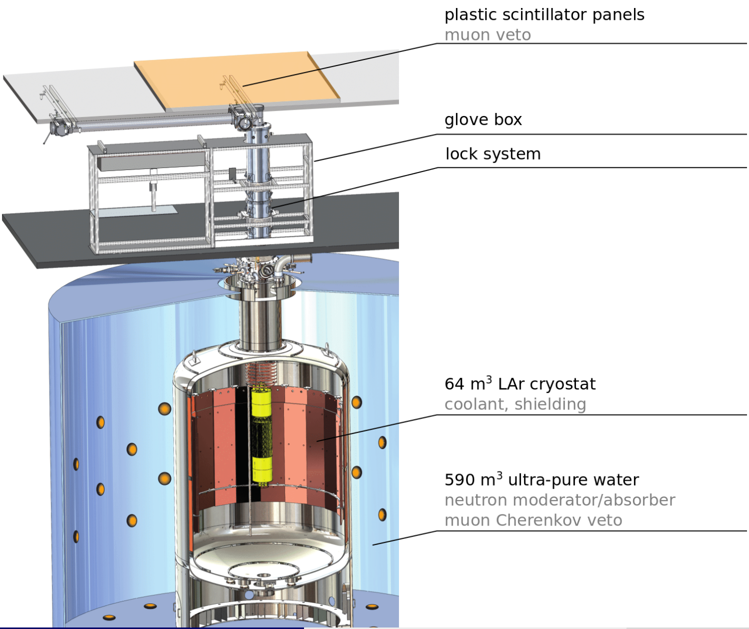
The GERDA collaboration

The GERDA experiment @ LNGS



3500 m.w.e rock overburden
$\rightarrow$ cosmic μ-flux reduced by a factor $\sim 10^6$
$\rightarrow 1\mu/m^2/h$

The GERDA experiment



From Phase I to Phase II

Phase I ($T^{0\nu}_{1/2} \propto \epsilon \cdot a \cdot \sqrt{\frac{M \cdot t}{BI \cdot \Delta E}}$)

- exposure:
  $17.9\,\mathrm{kg \cdot yr}$ enr. semi-coaxial (golden)
  $+ 1.3\,\mathrm{kg \cdot yr}$ enr. semi-coaxial (silver)
  $+ 2.4\,\mathrm{kg \cdot yr}$ enriched BEGe
- BI $\sim 10^{-2}\,\mathrm{cts/(kg\,keV\,yr)}$
- $T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}\,\mathrm{yr}$ 90% C.L.
  sensitivity $2.4 \cdot 10^{25}\,\mathrm{yr}$
  (PRL 111 (2013) 122503)

Phase II ($T^{0\nu}_{1/2} \propto \epsilon \cdot a \cdot M \cdot t$)

goals:

- reach $100\,\mathrm{kg \cdot yr}$ exposure
- BI $< 10^{-3}\,\mathrm{cts/(kg\,keV\,yr)}$

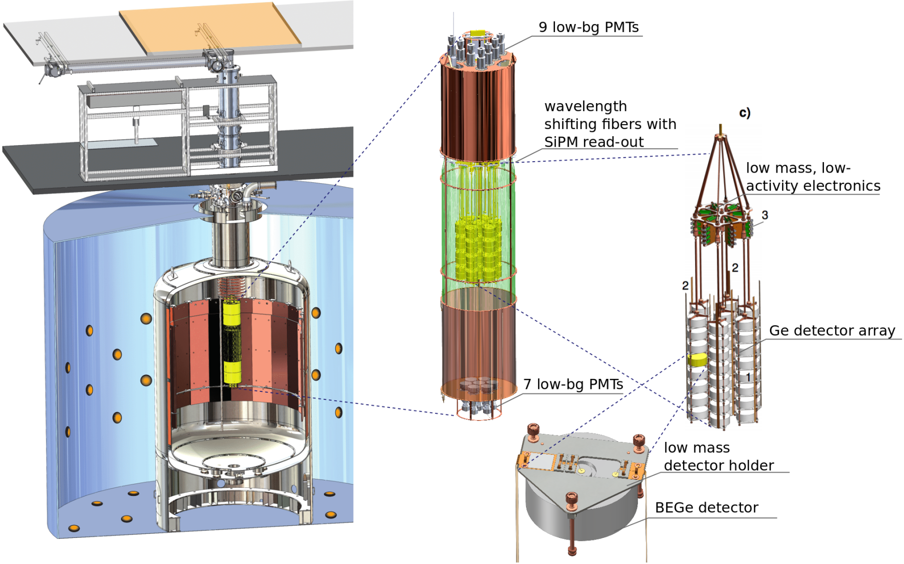
$\Rightarrow$ stay background free

$\Rightarrow$ reach sensitivity $> 10^{26}\,\mathrm{yr}$

strategy: increase mass / exposure and reduce BI

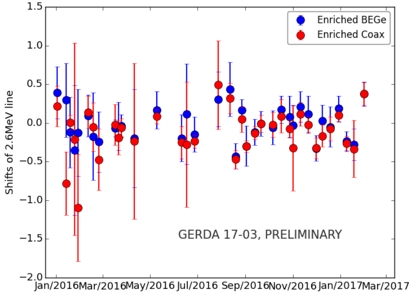
- mass: $20\,\mathrm{kg}$ (30) enr BEGe
  $15\,\mathrm{kg}$ (7) enr coaxial
- Novel detector technology with improved resolution
- BI: Background
  $\rightarrow$ material screening/reduction
  $\rightarrow$ enhanced PSD
  $\rightarrow$ LAr veto

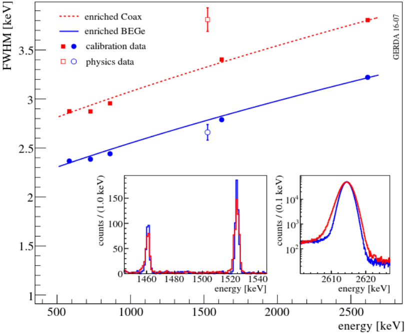
Phase II upgrade



Phase II: Data set, energy scale and resolution

- data set: December 2015 - May 2016, 85% duty cycle
- exposure: BEGes 5.8 $\mathrm{kg \cdot yr}$, coaxials 5.0 $\mathrm{kg \cdot yr}$



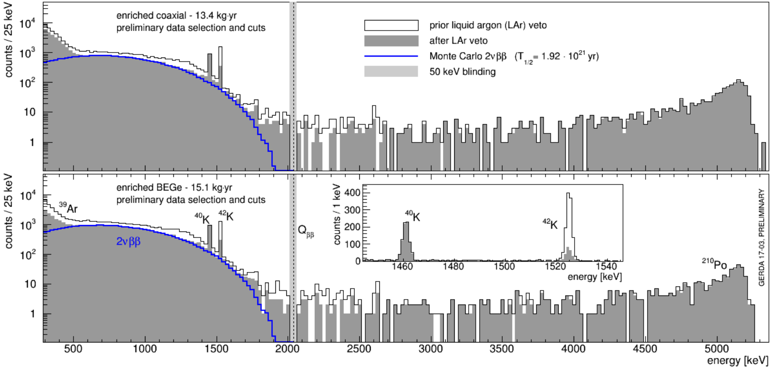


- FWHM @ $Q_{\beta\beta}$

BEGe: 3.0(2) keV

coax: 4.0(2) keV

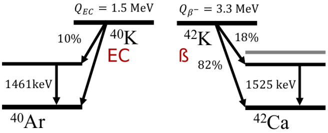
Physics data: LAr veto performance



pure $2\nu\beta\beta$ spectrum after LAr veto

$2\nu\beta\beta$:bg 97:3 $[(0.6-1.3)\,\mathrm{MeV}]$

sim. $2\nu\beta\beta$ w/ $T_{1/2}^{2\nu} = 1.9 \cdot 10^{21}\,\mathrm{yr}$



acceptance for test pulses (RC)

full data set: 97.7%

SF ~ 1
compatible with RC-rate

SF ~ 5
up to $2\,\mathrm{MeV}$ in LAr

Physics data: PSD performance

BEGes

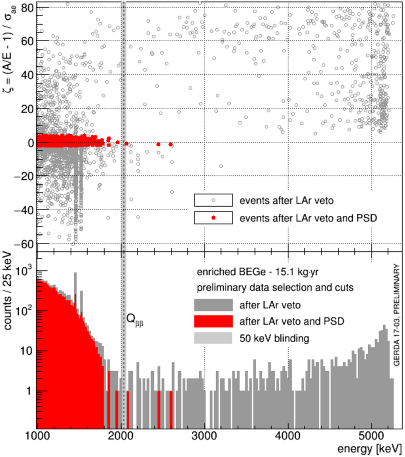
- based on mono-parametric *A/E* value
- tuned with calibration data

⇒ $0\nu\beta\beta$-acceptance $(87 \pm 2)\%$

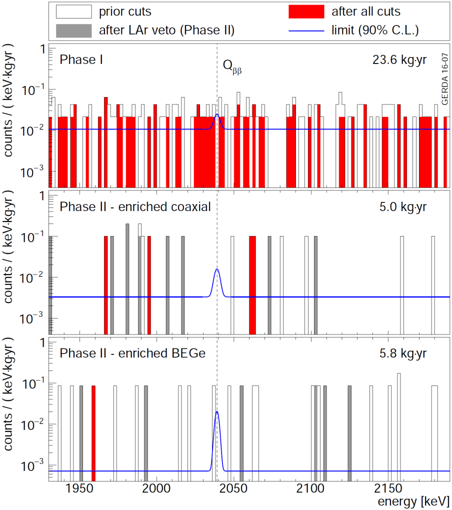
coaxial detectors

- artificial neural network
- MSE recognication tuned with calibration data (same as in Phase I)
- new α-event cut, tested/trained with sample from data

⇒ $0\nu\beta\beta$-acceptance $(79 \pm 5)\%$



New $0\nu\beta\beta$-decay $T_{1/2}$ limit

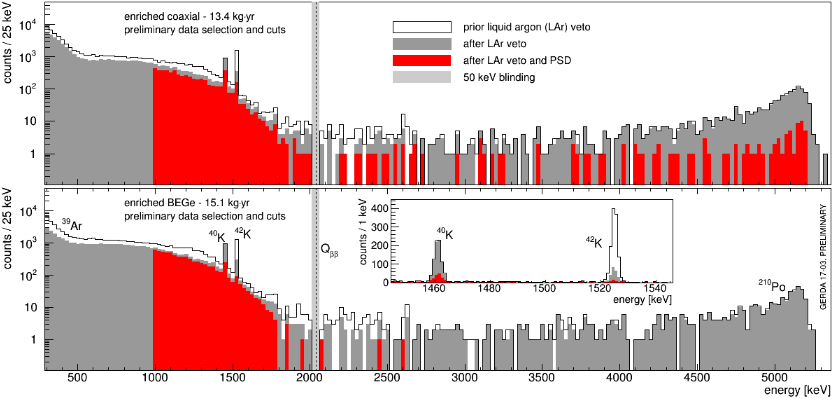


extended unbinned profile likehood:

- flat background in 1930 – 2190 keV
- signal = Gaussian with mean at $Q_{\beta\beta}$ and standard deviation σ_E
- 7 parameters: 6 BI + common $T_{1/2}$

- best fit for $N_{0\nu} = 0$
- lower limit $T^{0\nu}_{1/2} > 5.3 \cdot 10^{25}\,\mathrm{yr}$ with $T^{0\nu}_{1/2}$ sensitivity $4.0 \cdot 10^{25}\,\mathrm{yr}$ (90% C.L.)

Current status (preliminary)



	exposure [kg yr]	BI [10^{-3} cts/(kg keV yr)]	... after LAr	... after PSD	... after LAr + PSD
BEGe	15.1	$12.3^{+2.3}_{-1.8}$	$3.9^{+1.3}_{-1.0}$	$3.2^{+1.2}_{-0.9}$	$0.6^{+0.6}_{-0.4}$
Coax	13.4	$16.7^{+2.7}_{-2.3}$	$8.0^{+1.9}_{-1.6}$	$8.0^{+1.9}_{-1.6}$	$2.2^{+1.1}_{-0.8}$

Conclusions

- GERDA sets a new limit on the half-life of $0\nu\beta\beta$ decay of ^{76}Ge

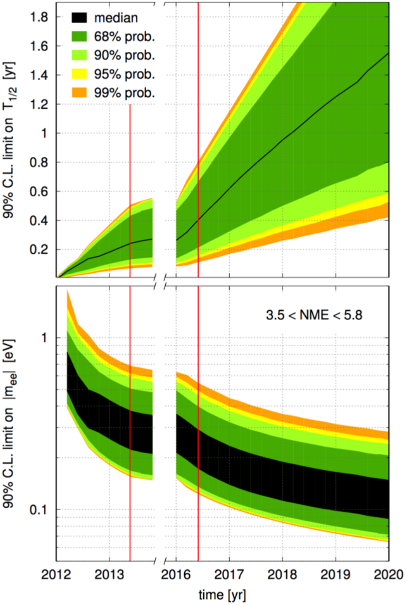
$$T_{1/2}^{0\nu} > 5.3 \cdot 10^{25}\,\mathrm{yr} \quad 90\%\ \mathrm{C.L.}$$

$$m_{\beta\beta} < (150 - 330)\,\mathrm{meV}$$

- best energy resolution: FWHM $= 3.0\,\mathrm{keV}$ $(4.0\,\mathrm{keV})$ BEGe (coax) at $Q_{\beta\beta}$
- flat background in ROI
- lowest background at $Q_{\beta\beta}$ $10^{-3}\,\mathrm{cts}/(\mathrm{keV\,kg\,yr})$

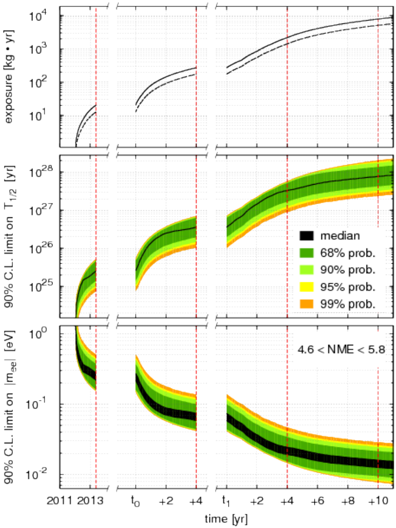
⇒ first background-free experiment

⇒ best conditions for a discovery



Beyond GERDA

- LEGEND (Large Enriched Germanium Experiment for Neutrinoless Double Beta Decay)
- new collaboration formed in Oct. 2016 (=GERDA + Majorana + new groups)
- goals:
  - ➢ LEGEND-200: 1st phase w/ 200 kg in existing infrastructure @ LNGS sensitivity $\approx 1 \cdot 10^{27}$ yr (exclusion + discovery)
  - ➢ LEGEND-1000: 1 t enriched Ge sensitivity $\approx 1 \cdot 10^{28}$ yr
  - $\Rightarrow$ remain background-free
  - $\Leftrightarrow$ LEGEND-1000: reduce background to ≤ 0.1 cts/(FWHM t yr)



[Eur.Phys.J.C76 (2016) 176]

Thank you for your attention !