A liquid Argon scintillation veto for the GERDA experiment

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1. The GERDA experiment
2. Light instrumentation of GERDA

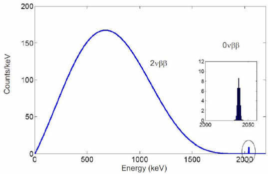
The GERDA experiment

Double beta decay

$^{76}\mathrm{Ge} \rightarrow {}^{76}\mathrm{Se} + 2e^{-} + 2\bar{\nu}_e$

$^{76}\mathrm{Ge} \rightarrow {}^{76}\mathrm{Se} + 2e^{-}$

Energy spectrum



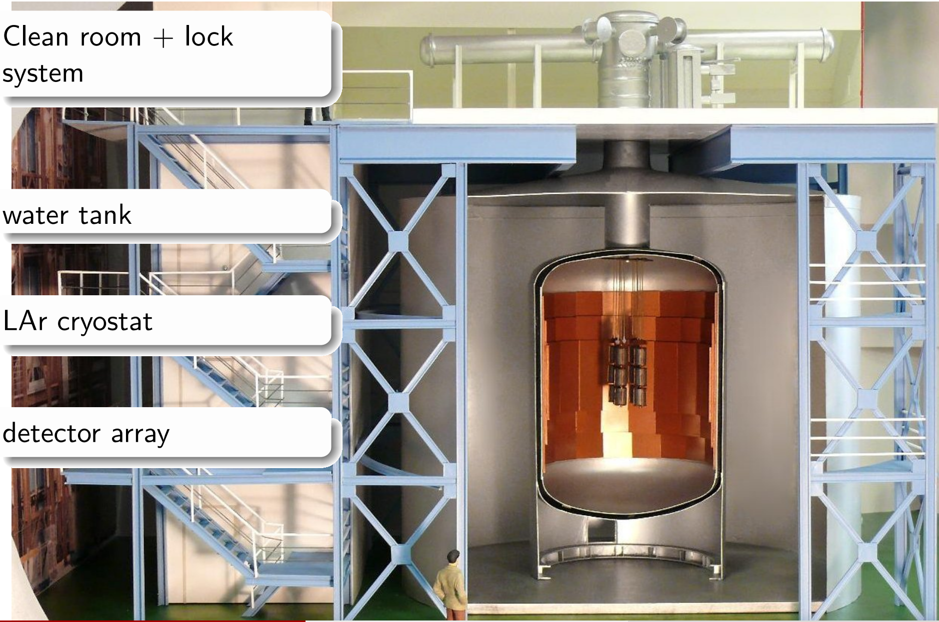
$T^{2\nu}_{1/2} = (1.84^{+0.14}_{-0.08})\,10^{21}$ yr arXiv:1212.3210

$T^{0\nu}_{1/2} = 1.19\,10^{25}$ yr Phys. Lett. **B586**,198 (2004)

Main challenge

fight background at $Q_{\beta\beta} = 2039\,\mathrm{keV}$

The GERDA experiment



Clean room + lock system

water tank

LAr cryostat

detector array

Background rejection in GERDA

Sensitivity to the lower limit of the half life scale of $0\nu\beta\beta$ decay

$$T_{1/2} \propto \epsilon a \sqrt{\frac{Mt}{BI\Delta(E)}}$$

ϵ: detection efficiency,
a: abundance of ^{76}Ge
Mt: exposure [kg yr],
BI: background index [$\mathrm{cts/(keV\,kg\,yr)}$],
$\Delta(E)$: energy resolution in ROI at $Q_{\beta\beta}$

currently running:

- start: november 2011
  planned end: summer 2013
- detector mass:
  $M_{\mathrm{coaxial}} = 17.7\,\mathrm{kg}$
  $M_{\mathrm{BEGe}} = 3.6\,\mathrm{kg}$
- energy resolution @ $2.6\,\mathrm{MeV}$:
  $\Delta E_{\mathrm{coaxial}} \approx 4.5\,\mathrm{keV}$
  $\Delta E_{\mathrm{BEGe}} \approx 3.0\,\mathrm{keV}$
- BI $\approx 2.4(3) \cdot 10^{-2}\,\mathrm{cts/(keV\,kg\,yr)}$

PhaseII

- additional $20\,\mathrm{kg}$ of enr Ge detectors (BEGe)
- cleaner and lighter detector holders, cables, ...

aspired BI $\leqslant 10^{-3}\,\mathrm{cts/(keV\,kg\,yr)}$

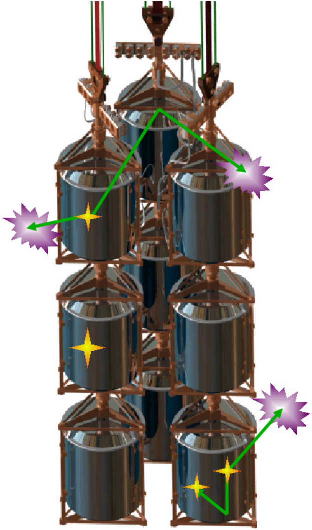
⇒ active background suppression methods are needed [T 109.4]

- ➢ detector anticoincidence
- ➢ water cherenkov veto
- ➢ pulse shape analysis [T 110.2, HK 66.6]
- ➢ **LAr scintillation veto** will be installed

LAr scintillation veto for background suppression

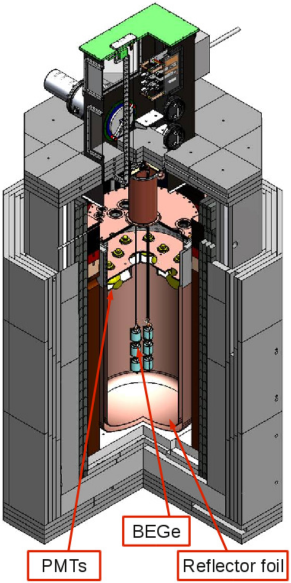
How does an active LAr veto work?

1. $0\nu\beta\beta$ event deposits its energy at one point in the Ge-crystal → not vetoed
2. surface beta (Bi214, K42)
   → often not vetoed by LAr veto (→ PSD)
3. γ background events in ROI (Bi214, Tl208)
   → can be vetoed
   - energy deposition in multiple crystals
     → detector anticoincidence veto
   - Multisite event
     → pulse shape discrimination veto
   - energy deposition inside the crystal and in LAr
     ⇒ create scintillation light @ $\lambda = 128\,\mathrm{nm}$
     ⇒ can be used as anticoincidence veto

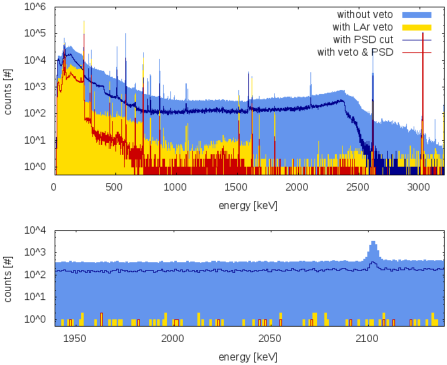


LArGe - a test facility for GERDA

Experimental verification



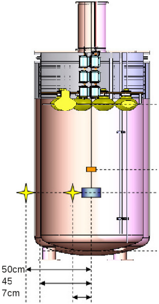
energy spectrum for an internal Th228 source:



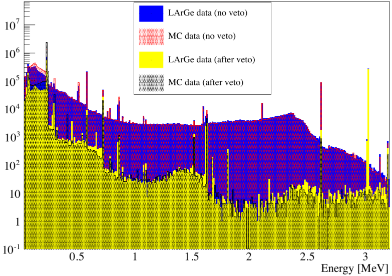
Suppression factors at $Q_{\beta\beta} \pm 35\,\mathrm{keV}$:
LAr ≈ 1200; PSD ≈ 2.4

LArGe - a test facility for GERDA

Monte Carlo validation & tuning of optical parameters



- simple geometry
- measurements available



- Tuning of optical properties
  - ➢ material reflectivities (Ge, Cu, VM2000, ...)
  - ➢ absorption and emission spectra
  - ➢ LAr attenuation length, light yield and triplet lifetime
- good MC description after tuning

Bg	LArGe data	MC
	internal	
Tl208	1180 ± 250	909 ± 235
Bi214	4.6 ± 0.2	3.8 ± 0.1
Co60	27 ± 2	16.1 ± 1.3
	external	
Tl208	25 ± 1.2	17.2 ± 1.6
Bi214	3.2 ± 0.2	3.2 ± 0.4

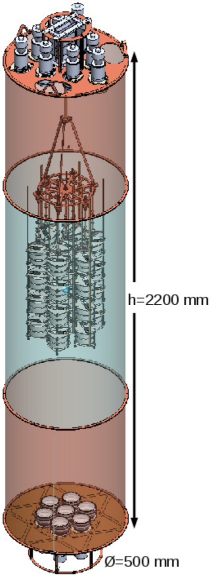
Light instrumentation for GERDA

"Hybrid" LAr veto design

- result of MC simulation optimization campaign
- uses combination of PMTs and scintillation fibers to read-out the scintillation light [T109.2]

Requirements on light instrumentation

- big instrumented volume
- low instrumentation induced background index
  - Photomultiplier
  - Wavelength shifting fibers
  - wavelength shifting and reflective foil
- applicable without LAr drainage



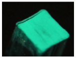
“Hybrid” LAr veto design

Photomultiplier

- type: 3 “ R 11065-10/-20
- 9* top, 7* bottom

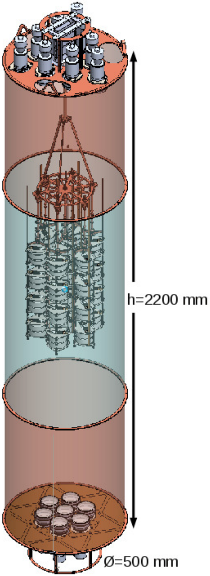
Scintillating fibers [T 109.2]

- build the middle shroud
- type: BCF-91A coated with TPB
- light readout at upper end by SiPMs

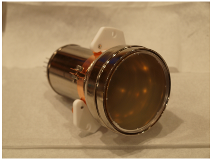


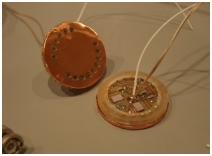
Copper shroud + reflective foil

- Tetratex coated with TPB [HK 46.8]
- installed on inner side of copper shrouds



Photomultiplier - Hardware





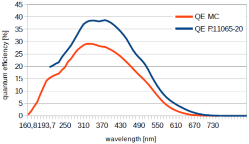
screening results [mBq/pc]

	Th228	Ra226
PMT *	< 1.94	< 1.7
VD	< 0.5	< 1.14

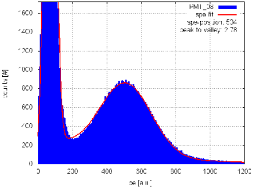
* calculated from component screening

currently screening of 6 R11065-10 PMTs

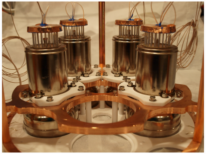
R11065-20 has higher QE than R11065-10

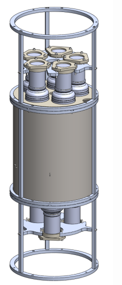


peak-to-valley:



Teststand

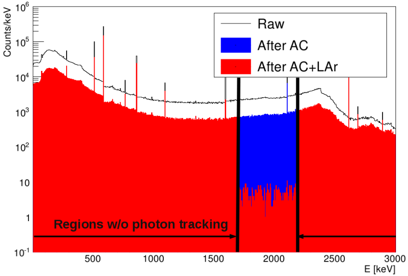




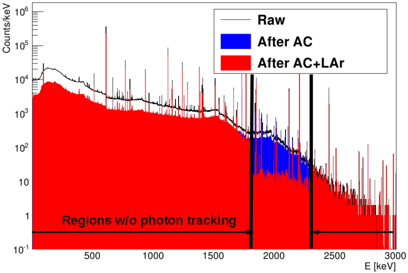
- test of up to 10 PMTs in LAr
- light yield measurements
- gain measurements

“Hybrid” LAr veto design - MC simulations

Tl208 in holders:



Bi214 in holders:



suppression factors

	Holders	Surface	Homogenous	External
*Bi*214	10.3 ± 0.3	3.5 ± 0.1	54.8 ± 7.9	-
*Tl*208	320 ± 34	-	-	112.1 ± 38.8

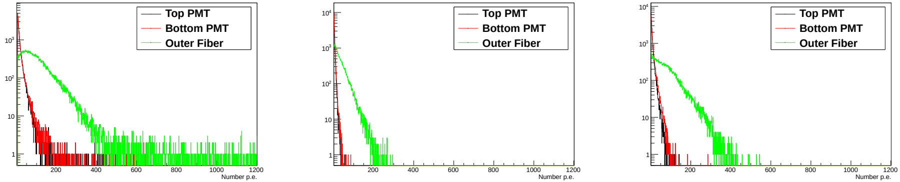
“Hybrid” LAr veto design - MC simulations

Systematics studies

- changed attenuation for XUV light and metal reflectivities dramatically

	Baseline	Attenuation * 0.2	Reflectivity * 0.1
Bi214 in holders	10.3 ± 0.3	8.9 ± 0.3	9.4 ± 0.3

⇒ LAr veto gives still good suppression factors
but p.e. yield drops



“Hybrid” LAr veto design

Instrumentation induced BI $[\mathrm{cts/(keV\,kg\,yr)}]$

background source		Activity	BI w/o LAr veto	BI with LAr veto *
PMTs + VD	Th228	$< 2.44\,\mathrm{mBq/PMT}$	$< 3.1(1) * 10^{-4}$	$< 3.1(5) * 10^{-6}$
	Ra226	$< 2.84\,\mathrm{mBq/PMT}$	$< 5.5(2) * 10^{-5}$	$< 2.7(5) * 10^{-6}$
cable	Th228	$< 14.4\,\mu\mathrm{Bq/m}$	$< 2.4(1) * 10^{-4}$	$< 7.0(2) * 10^{-6}$
	Ra226	$< 11.2\,\mu\mathrm{Bq/m}$	$< 3.9(1) * 10^{-5}$	$< 5.5(2) * 10^{-6}$
top & bottom shroud (Tetratex & copper)	Th228	$< 103\,\mu\mathrm{Bq/m^2}$	$< 2.7(1) * 10^{-5}$	$< 9.9(5) * 10^{-7}$
	Ra226	$< 282\,\mu\mathrm{Bq/m^2}$	$< 1.2(1) * 10^{-5}$	$< 1.5(1) * 10^{-6}$
sum	Th228		$< 5.8(1) * 10^{-4}$	$< 1.1(1) * 10^{-5}$
	Ra226		$< 1.1(1) * 10^{-4}$	$< 9.8(6) * 10^{-6}$
	total		$< 6.8(1) * 10^{-4}$	$< 2.1(1) * 10^{-5}$

* determined with older geometry, will improve a bit

Summary

- Installation of LAr scintillation veto is planned for PhaseII of GERDA
- Hybrid design using scintillating fibers and PMTs is the baseline option
    - hardware tests are ongoing
    - construction has started
- extensive MC simulation campaign performed
    - used LArGe for validation and tuning
    - provided optimizations to the hardware design
- LAr veto suppression factors look promising:
    - ➢ $> 10^2$ for Th228 ($\approx$ 300 close by, $\approx$ 100 far from detectors)
    - ➢ $\approx$ 10 for nearby Ra226 background source
- Instrumentation induced BI within the budget

Thanks for your attention !

“Hybrid” LAr veto design - MC simulations

Veto efficiencies for different background sources are estimated by Monte Carlo simulations

- MaGe (Geant4) based simulation of nuclear decays
- If event passes cuts on energy deposition in the Ge crystals, optical photons created in the LAr are propagated. Otherwise event is discarded
  - ➢ photons are tracked inside the wls fiber
  - ➢ green shifted photons in the fiber can reach the PMTs
- reflectivity and surface roughness of the surrounding materials are implemented