Development for photomultiplier light instrumentation for the GERDA experiment

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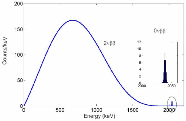
LAr scintillation veto for background suppression

GERDA experiment is searching for neutrinoless double beta ($0\nu\beta\beta$) decay of ^{76}Ge at $Q_{\beta\beta} = 2039\,\mathrm{keV}$



aspired background index [BI]

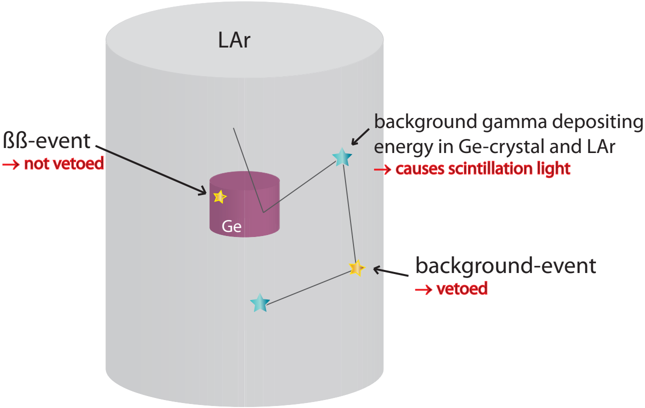
currently: $BI \approx 1.7 \cdot 10^{-2}\,\mathrm{cts/(kg\,y\,keV)}$
Phase II: $BI \leqslant 10^{-3}\,\mathrm{cts/(kg\,y\,keV)}$

To reach goal of Phase II active background suppression methods are needed

- ➢ pulse shape analysis [see 116.4]
- ➢ LAr scintillation veto

LAr scintillation veto for background suppression

How does an active LAr veto work?



⇒ light can be used as an anti-coincidence veto

Principle has been proven by LArGe (test facility for GERDA at LNGS)

talk by M. Heisel [T 116.1]

LAr veto with PMTs

goal of light instrumentation:
effective suppression of γ background in ROI

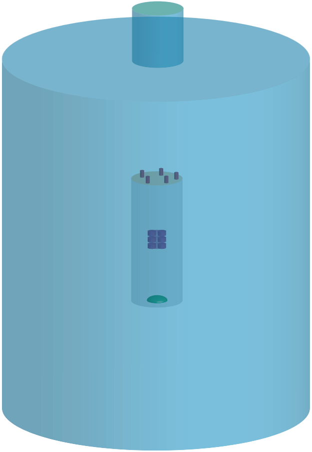
what do we need?
general:

- big instrumented volume
- low instrumentation induced background index

baseline design using photomultipliers:

- fits current flange diameter to avoid LAr drainage
  $\Rightarrow \varnothing = 500\,\mathrm{mm},\ h = 2100\,\mathrm{mm}$
- needs reflective and wavelength shifting foil on inner cylinder surface
  (VM2000 coated with wavelength shifter)

baseline design:



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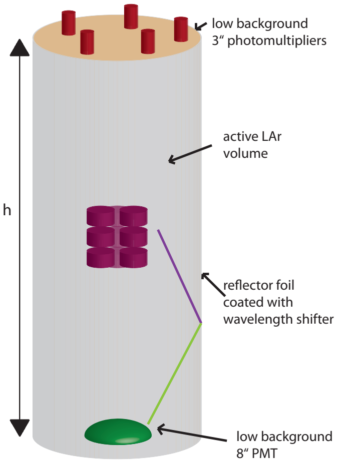


Photomultiplier

R5912-02 MOD: (8-inch)

- QE 25% @ 390 nm
- bialkali photocathode (sandblasted)
- low bg-version

activity [mBq/PMT]

^{228}Th	^{238}U
165	374

R11065-10 MOD: (3-inch)

- QE 25% @ 420 nm
- bialkali photocathode (sandblasted)
- ultra-low bg-version

activity [mBq/PMT]

^{228}Th	^{238}U
1.0	$\leqslant$ 0.94

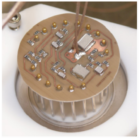
Photomultiplier

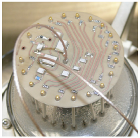
inserted in cryostat filled with LAr

Photomultiplier

preliminary results show good performance
→ long term tests in LAr are ongoing

low background voltage divider





operational in LAr
negative bias HV

high dynamic range

Wavelength shifting reflector foil

proven technology from LArGe facility

Monte Carlo simulations of typical γ backgrounds

Geant4 simulations using the framework **MaGe**

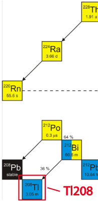
Some facts about the applied veto cut

Add up the energy at each interaction point if it is deposited inside the instrumented LAr volume

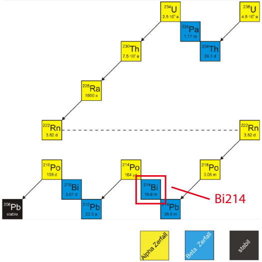
If total deposited energy in the active LAr volume $\geqslant E_{threshold} = 100\,\mathrm{keV}\ (10\,\mathrm{keV})$
$\Rightarrow$ **VETO the event**

Typical γ backgrounds:

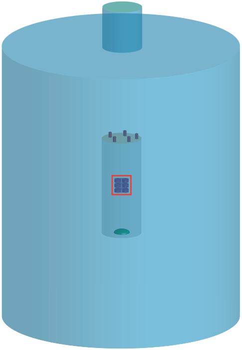
Th232-chain:

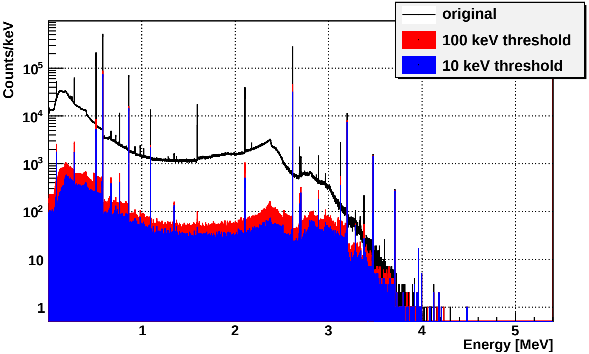


U238-chain:



Tl208 | Detector support



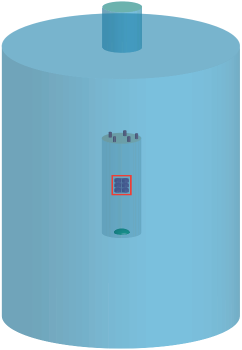


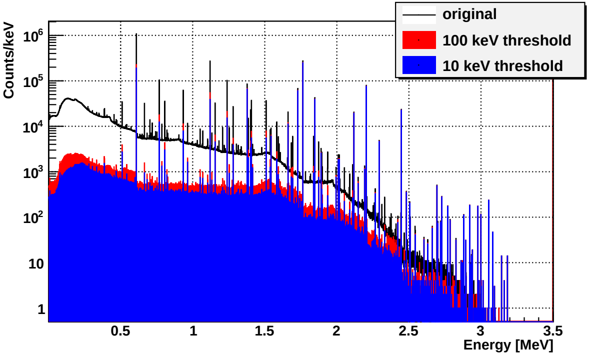
suppression factors at $Q_{\beta\beta}$:

$$E_{threshold} = 100\,\mathrm{keV} \Rightarrow SF = 32$$

$$E_{threshold} = 10\,\mathrm{keV} \Rightarrow SF = 58$$

Bi214 | Detector support

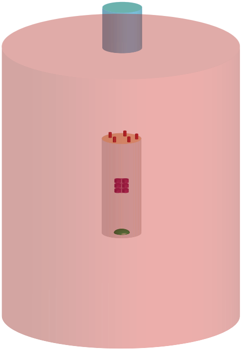


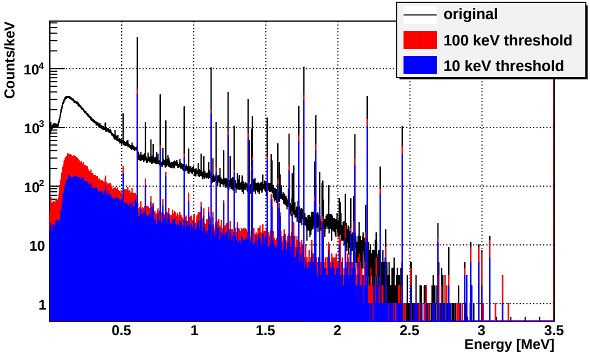


suppression factors at $Q_{\beta\beta}$:

$$E_{threshold} = 100\,\mathrm{keV} \Rightarrow SF = 3.3$$
$$E_{threshold} = 10\,\mathrm{keV} \Rightarrow SF = 5.6$$

Bi214 | homogenous distribution in LAr



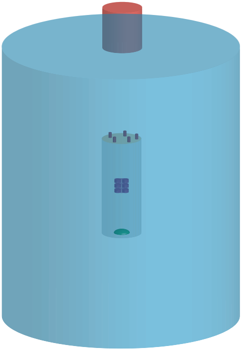


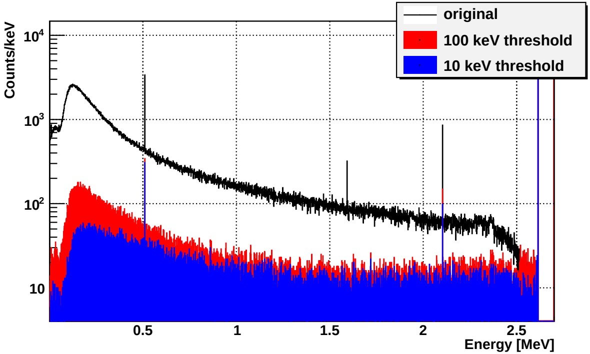
suppression factors at $Q_{\beta\beta}$:

$$E_{threshold} = 100\,\mathrm{keV} \Rightarrow SF = 6.9$$

$$E_{threshold} = 10\,\mathrm{keV} \Rightarrow SF = 13$$

Tl208 | Source far away





suppression factors at $Q_{\beta\beta}$:

$$E_{threshold} = 100\,\mathrm{keV} \Rightarrow SF = 4.6$$

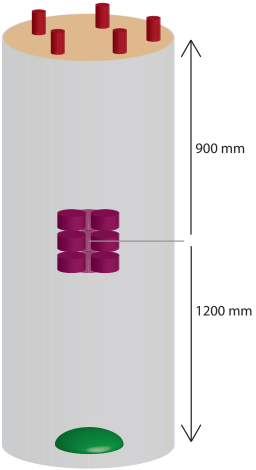
$$E_{threshold} = 10\,\mathrm{keV} \Rightarrow SF = 6.1$$

Tl208 and Bi214 | Suppression factors

Summary | Suppression factors in baseline design

	Tl208		Bi214	
	100 keV	10 keV	100 keV	10 keV
Detector Holders	32	58	3.3	5.6
homogenous distribution in LAr	-	-	6.9	13
Source far away	4.6	6.1	-	-

PMT induced background



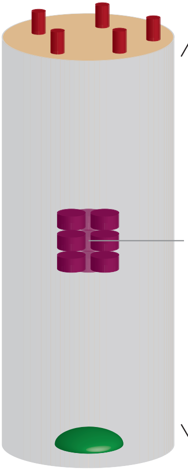
3" PMT activity (measured)

Tl208: 0.36 $\mathrm{mBq/PMT}$
Bi214: $\leqslant$ 0.94 $\mathrm{mBq/PMT}$

8" PMT activity (measured)

Tl208: 59 $\mathrm{mBq/PMT}$
Bi214: 374 $\mathrm{mBq/PMT}$

PMT induced background



BI induced by 3" PMTs (MC)

	BI $[10^{-3}\mathrm{cts/(kg \cdot y \cdot keV)}]$ w/o veto	w veto	SF (100 keV)
Tl208	0.17	0.006	28
Bi214	$\leqslant$ 0.025	$\leqslant$ 0.004	6.0

total induced BI

	w/o veto	w veto
Tl208	0.97	0.025
Bi214	0.27	0.042
total	1.24	0.067

BI induced by 8" PMT

	w/o veto	w veto	SF (100 keV)
Tl208	0.8	0.019	41
Bi214	0.24	0.038	6

[preliminary]

Summary

- Hardware for baseline LAr instrumentation option using photomultipliers under preparation (low background PMTs and voltage dividers, wavelength shifter, DAQ)

➢ proceed with hardware tests

- LAr instrumentation in baseline design provides valuable background reduction in GERDA: e.g.
  Tl208 (internal): $SF = 32$
  Bi214 (internal): $SF = 3.3$
  (MC result with $E_{threshold} = 100\,\mathrm{keV}$)

➢ re-run simulations with photon tracking
$\Rightarrow$ includes shadowing effects and absorption

- instrumentation induced background (incl. self-vetoing) is within GERDA background specifications (MC result)

➢ LAr veto designs using scintillation fibers, SiPMs are discussed talk by: M. Heisel [T 116.1]

➢ MC benchmarks for a LAr veto design: N. Barros [T 109.5]

Thanks for your attention !

Suppression factor vs. threshold | Detector support