A liquid argon scintillation veto for the GERDA experiment

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- DPG Frühjahrstagung, 24.03.2014 -

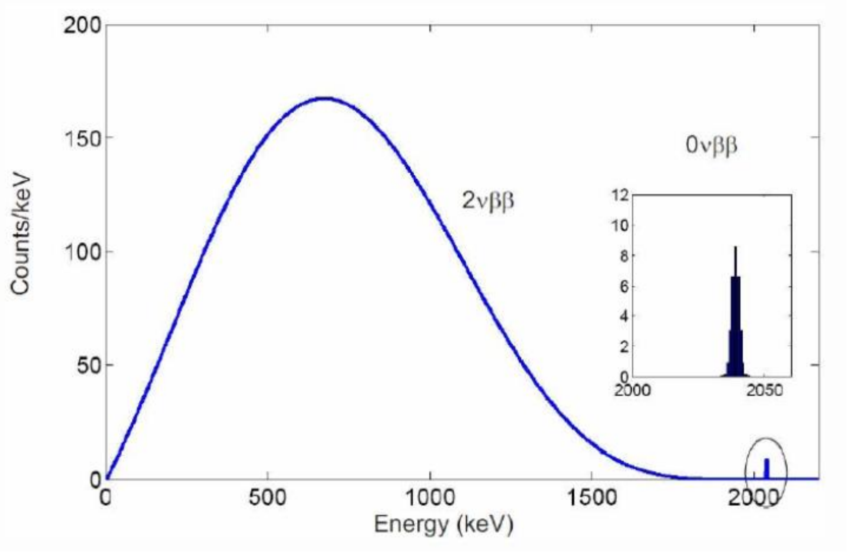
Double beta decay in ^{76}Ge

- $2\nu\beta\beta$: $^{76}Ge \rightarrow {}^{76}Se + 2e^{-} + 2\bar{\nu}_e$
- $0\nu\beta\beta$: $^{76}Ge \rightarrow {}^{76}Se + 2e^{-}$
  - $\Delta L = 2$
  - beyond SM

→ rare event search

- Energy spectrum:
  - continuous $2\nu\beta\beta$
  - peak @ $Q_{\beta\beta} = 2039\ keV$

- Sensitivity: $T_{1/2}^{0\nu} \sim \sqrt{\frac{M * t}{BI * \Delta E}}\ [yr]$

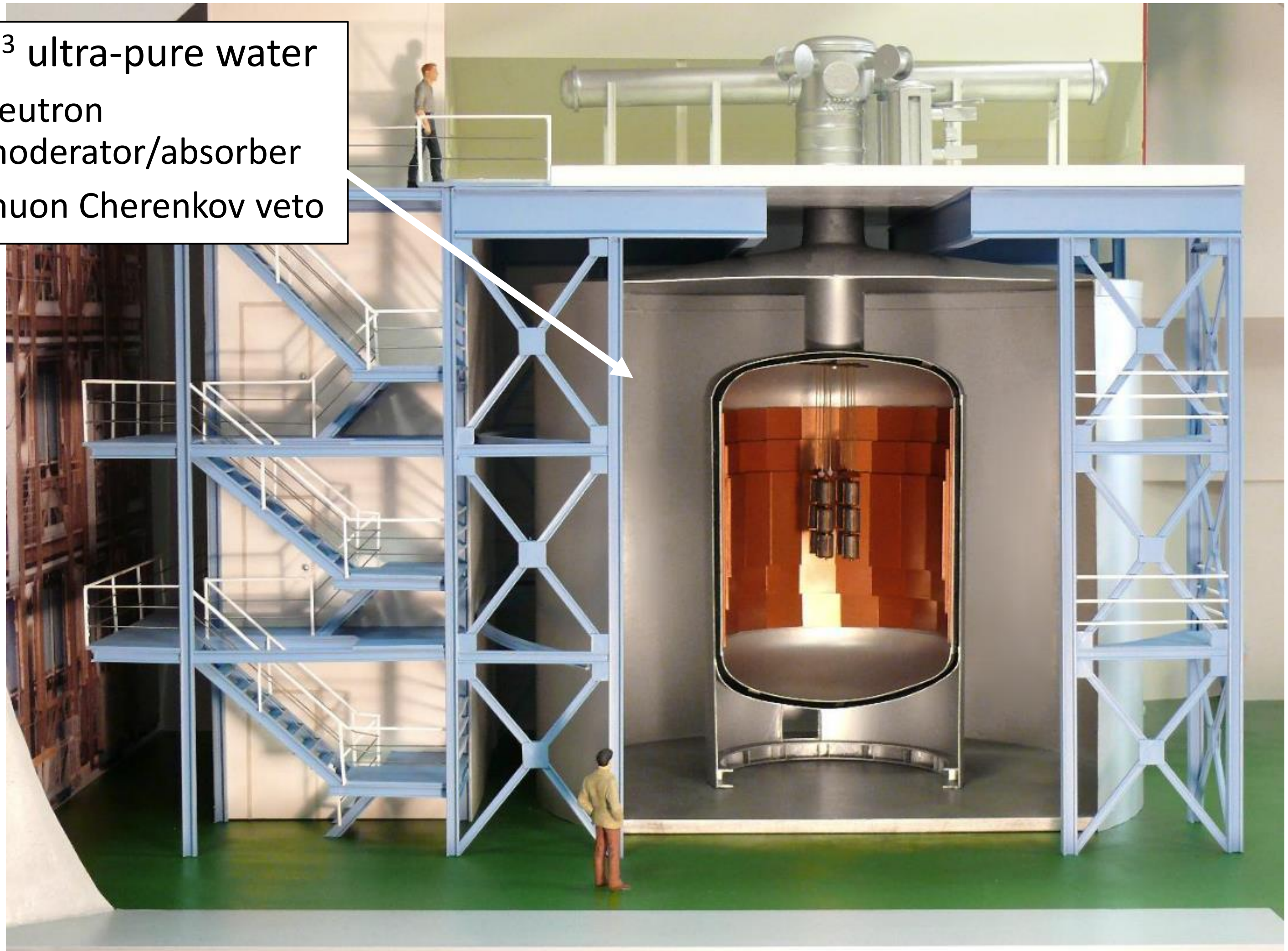


- Improve limit by:
  - more mass
  - measure longer
  - better energy resolution
  - **<u>lower background</u>**

The GERDA experiment

The GERDA experiment

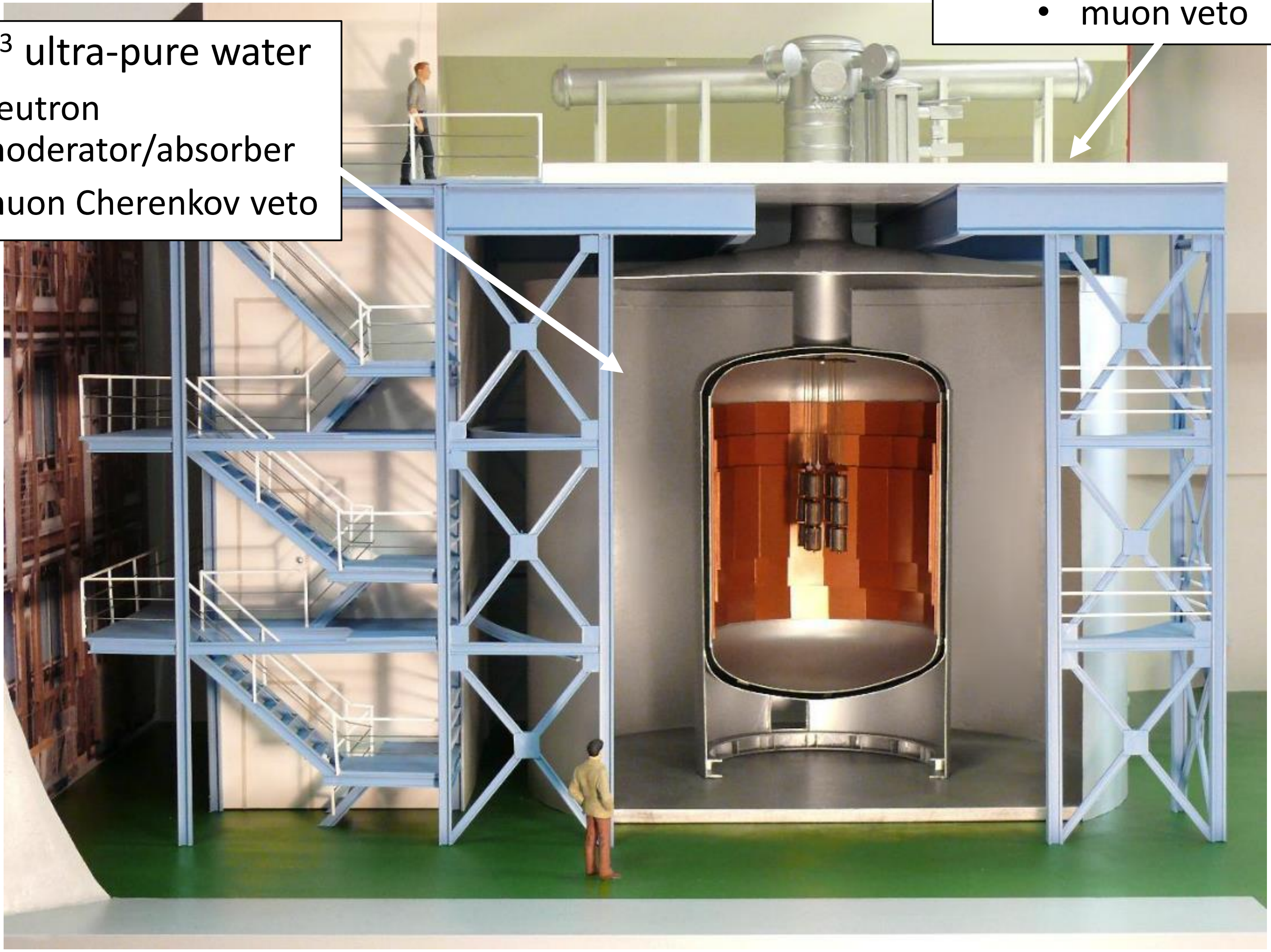
- 590 m³ ultra-pure water
  - neutron moderator/absorber
  - muon Cherenkov veto



The GERDA experiment

- 590 m^3 ultra-pure water
  - neutron moderator/absorber
  - muon Cherenkov veto

- plastic scintillator panels
  - muon veto

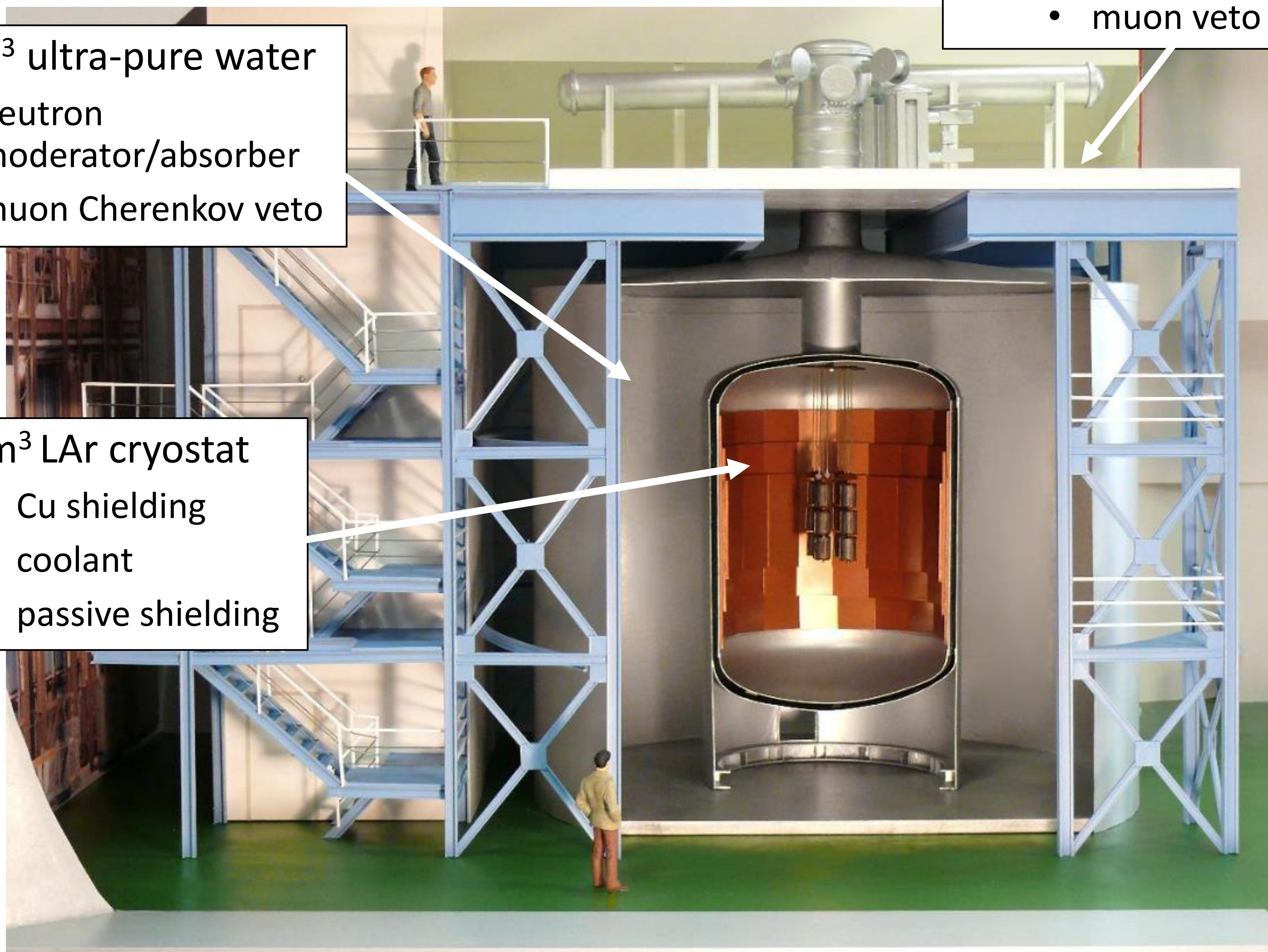


The GERDA experiment

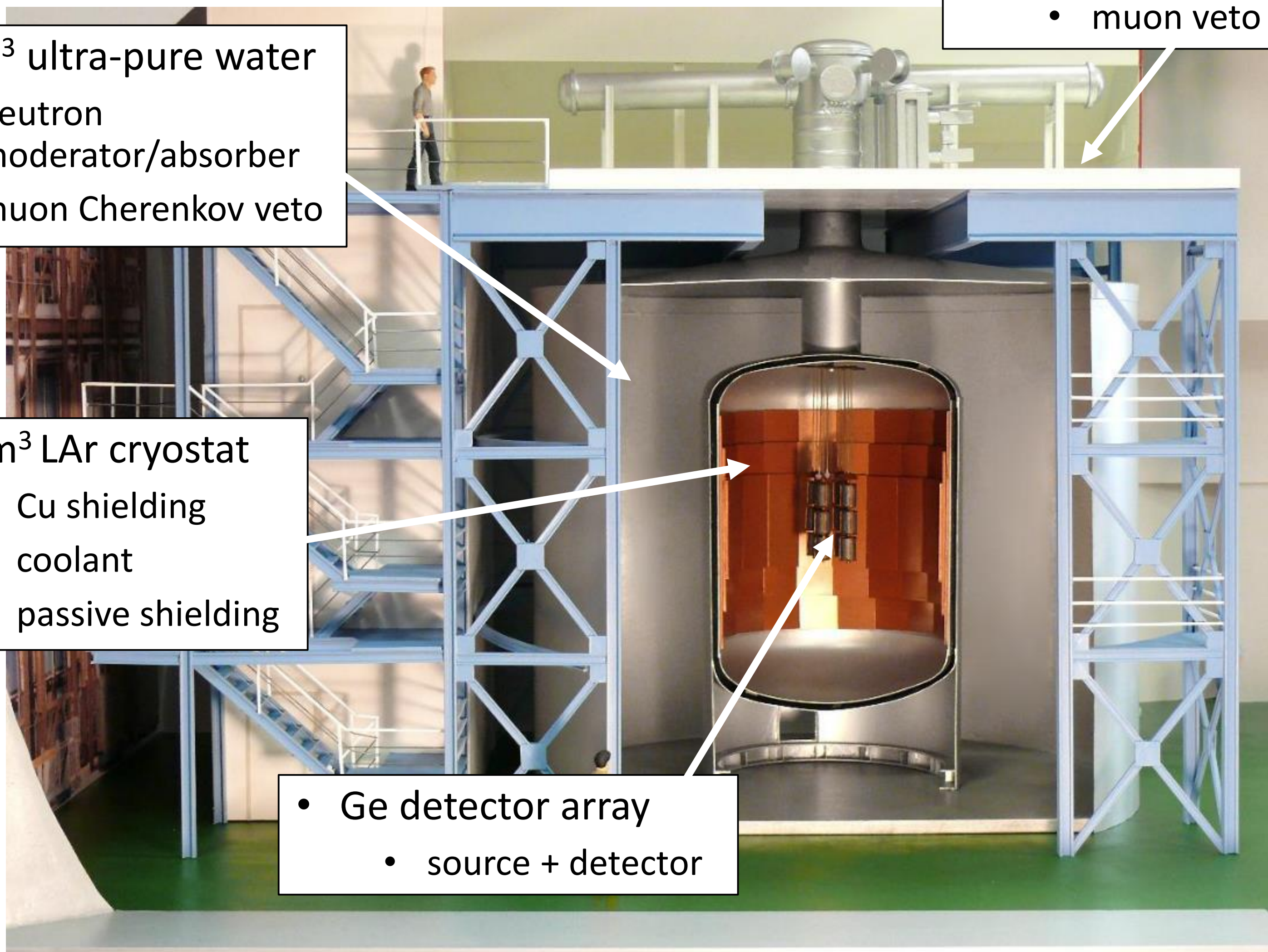
- 590 m^3 ultra-pure water
  - neutron moderator/absorber
  - muon Cherenkov veto

- plastic scintillator panels
  - muon veto

- 64 m^3 LAr cryostat
  - Cu shielding
  - coolant
  - passive shielding

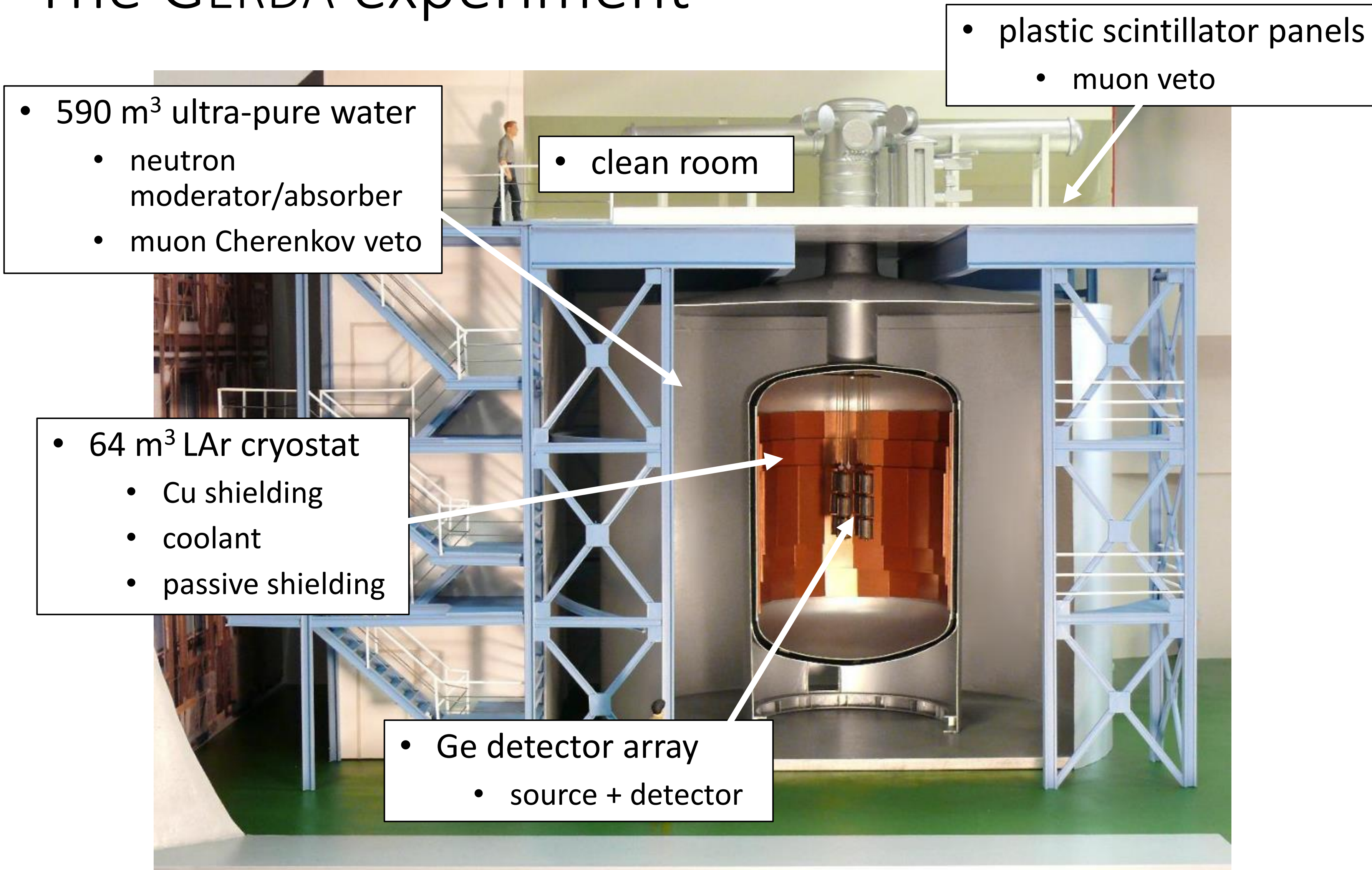


The GERDA experiment

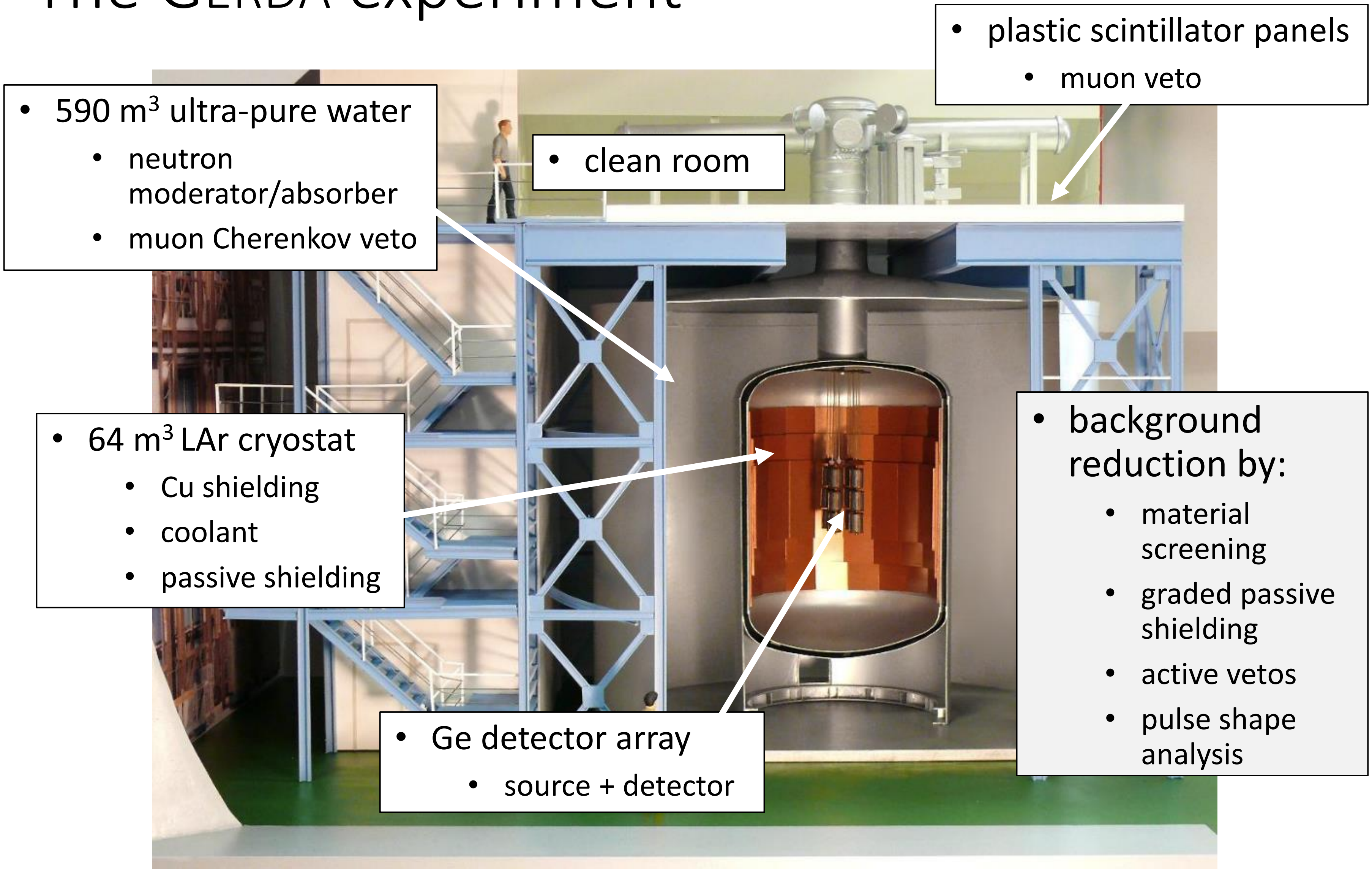


- plastic scintillator panels
  - muon veto
- 590 m^3 ultra-pure water
  - neutron moderator/absorber
  - muon Cherenkov veto
- 64 m^3 LAr cryostat
  - Cu shielding
  - coolant
  - passive shielding
- Ge detector array
  - source + detector

The GERDA experiment



The GERDA experiment



Results of GERDA Phase I

- November 2011 – May 2013
- Mass of operational detectors
  - $M_{coaxial, enr}$ = 14.63 kg
  - $M_{coaxial, enr}$ = 2.96 kg
  - M_{BEGe} = 3.00 kg
- Energy resolution @ 2.6 MeV (FWHM)
  - $\Delta E_{coaxial}$ ≈ 4.2 – 5.5 keV
  - $\Delta E_{coaxial}$ ≈ 2.6 – 4.0 keV
- Background index B ≈ 0.01 cts/(keV kg yr) after PSD

- $T_{1/2}^{2\nu} = (1.84^{+0.14}_{-0.08}) * 10^{21}\ yr$

J. Phys. G: Nucl. Part. Phys. 40 (2013) 035110

- $T_{1/2}^{0\nu} > 2.1 * 10^{25}$ yr (90% C.L.)

Phys. Rev. Lett 111 (2013) 122503

see: T65.1

Phase II

- additional 20 kg of enriched Ge detectors (BEGe)
- cleaner / lighter holders, …

- aspired Background index B ≤ 10^{-3} cts/(keV kg yr)

→ active background suppression needed!

  - detector anticoincidence
  - water Cherenkov veto
  - pulse shape analysis (see T18.1 / T105.4)
  - **<u>LAr scintillation veto</u>**

LAr scintillation veto for background suppression

- $0\nu\beta\beta$ event

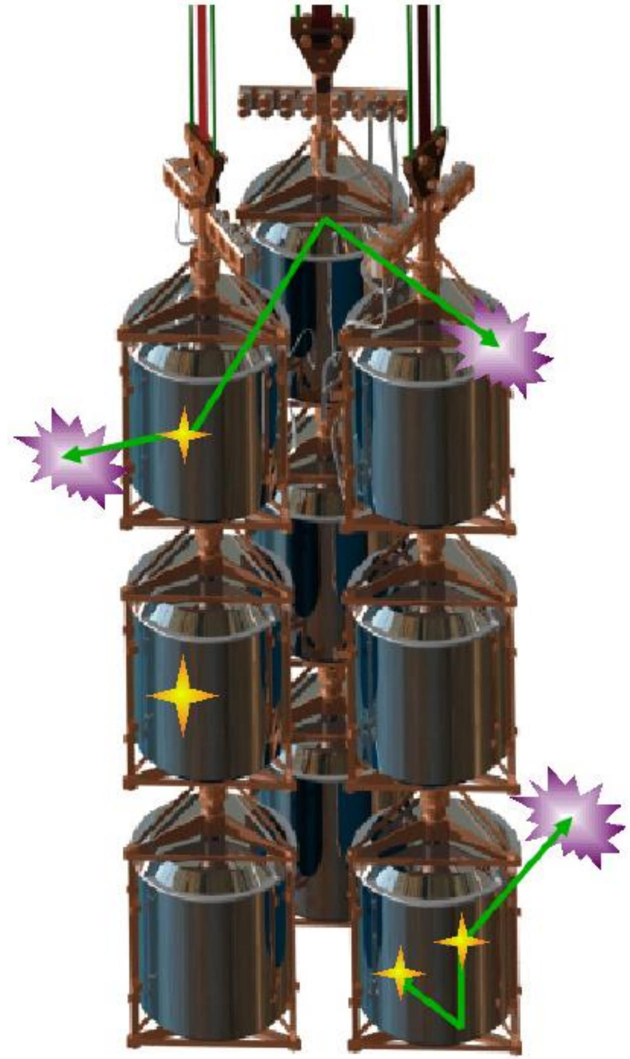
→ single site event, not vetoed

- surface beta (Bi214, K42)

→ often not vetoed by LAr veto (but PSD)

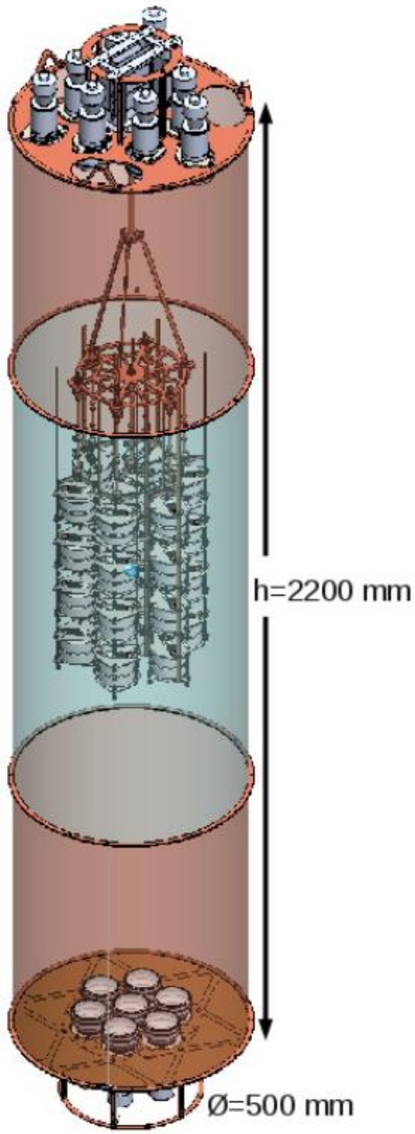
- γ background in ROI (Bi214, Tl208)

→ detector anticoincidence, PSD or **<u>LAr anticoincidence veto</u>**



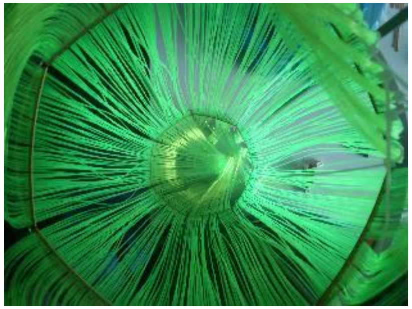
Active liquid argon veto design

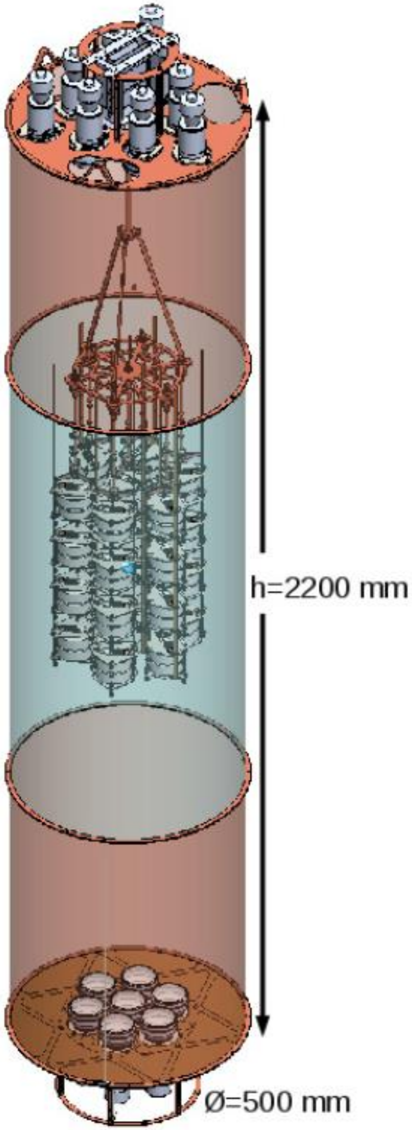
- Result of MC simulation optimization campaign
- Requirements:
  - big instrumented volume
  - low induced background index
  - applicable without LAr drainage
- Hybrid design: PMTs + scintillation fibers with SiPMs



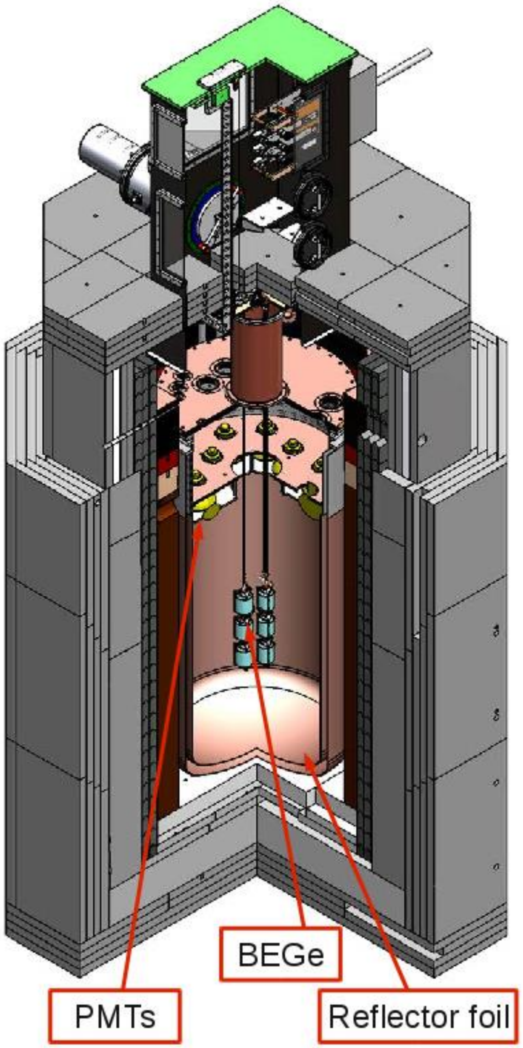
Active liquid argon veto design

- PMTs:
  - type: 3‘‘ R 11065-10/-20
  - 9 on top, 7 at bottom
- Scintillating fibers
  - type: BCF-91A coated with TPB
  - read out with SiPMs
- Copper shroud + reflective foil
  - Tetratex coated with TPB

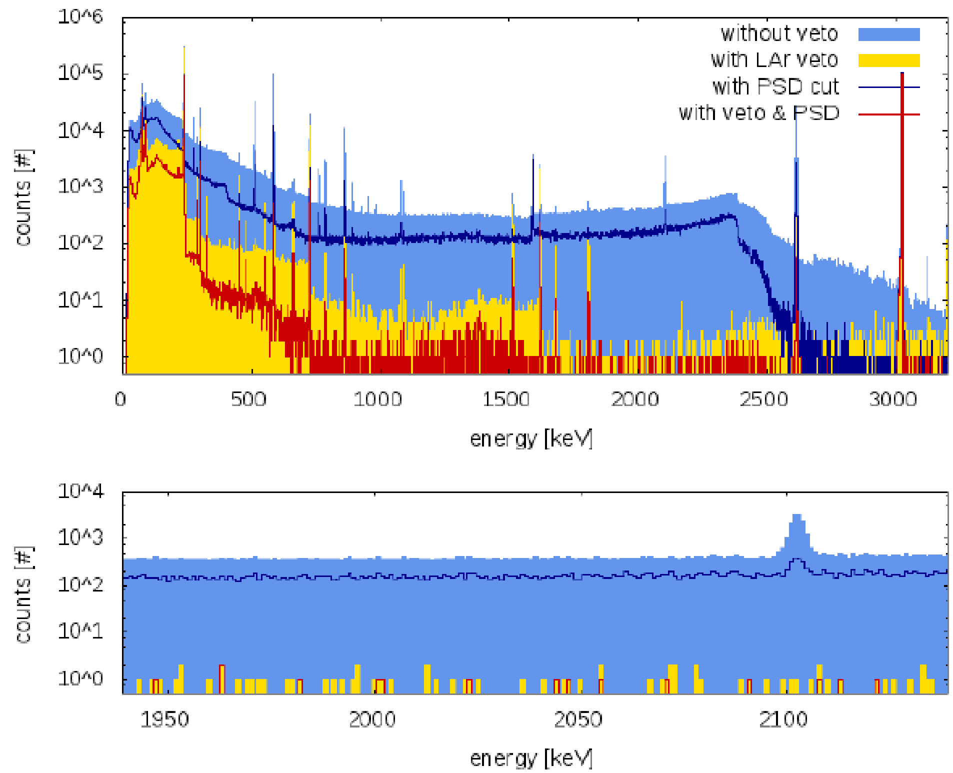




LArGe test facility



energy spectrum for an internal Th228 source:



- suppression factors at $Q_{\beta\beta} \pm 35$ keV:

  LAr ≈ 1200; PSD ≈ 2.4

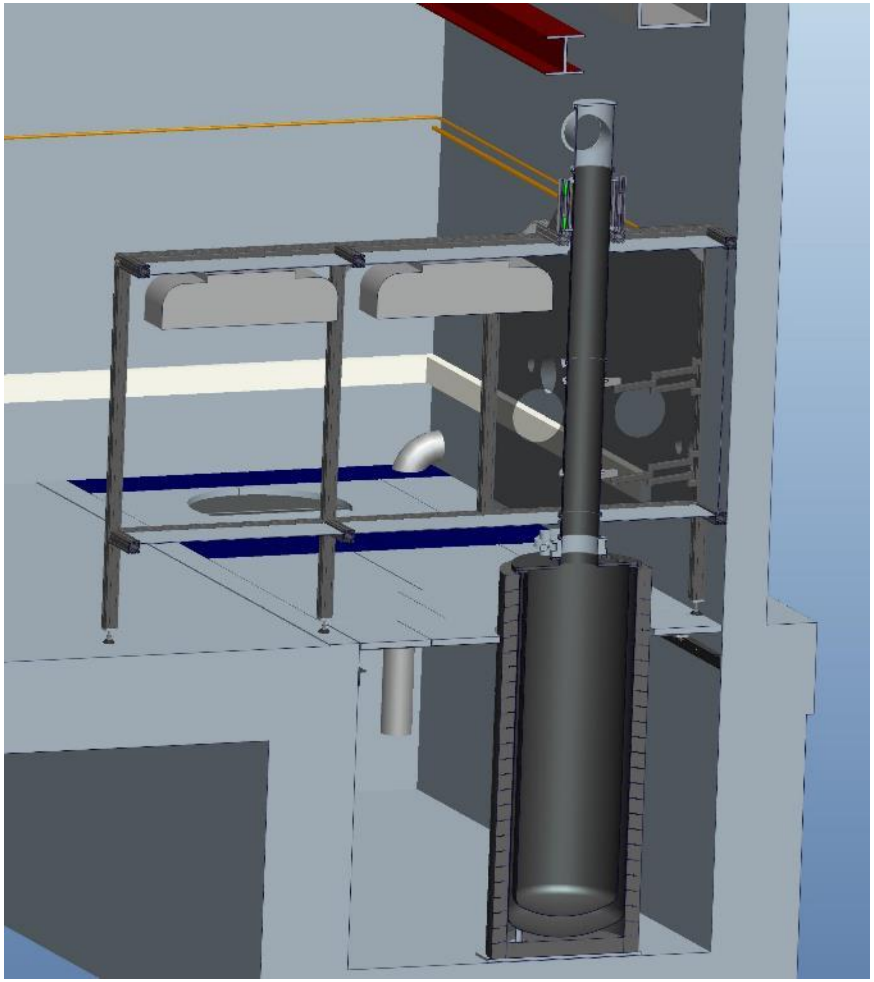
LArGe – Summary of suppression factors

source	position	suppression factor		
		LAr veto	PSD	total
^{60}Co	int	27 ± 1.7	76 ± 8.7	3900 ± 3000
^{226}Ra	ext	3.2 ± 0.2	4.4 ± 0.4	18 ± 3
	int	4.6 ± 0.2	4.1 ± 0.2	45 ± 5
^{228}Th	ext	25 ± 1.2	2.8 ± 0.1	129 ± 15
	int	1180 ± 250	2.4 ± 0.1	5200 ± 2300

Ref. M. Heisel, PhD thesis, 2011

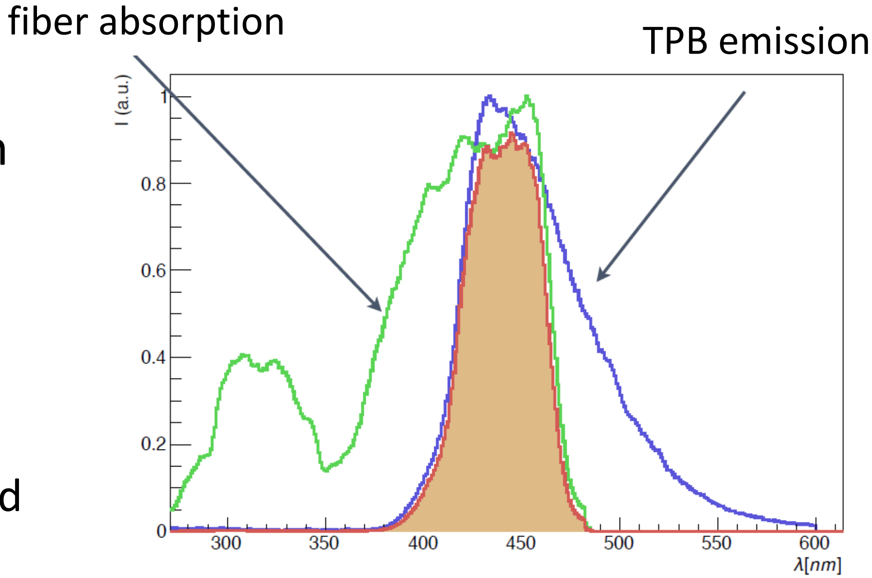
- Acceptance for $\beta\beta$-events:
  - LAr veto > 97%
  - PSD 90%

TUM cryostat

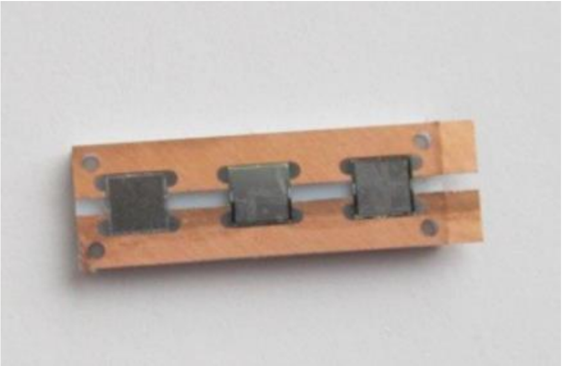


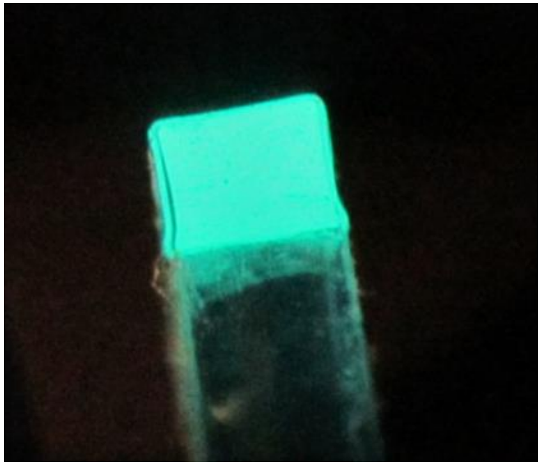
Fibers & SiPMs

- Wavelength shifter: 128 nm → 430 nm
  - detected with PMT
  - collected by fibers



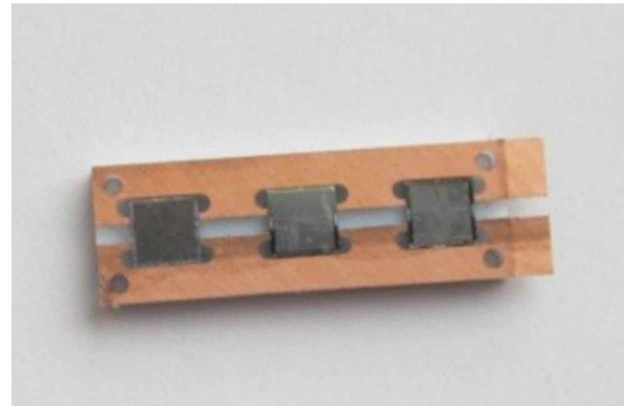
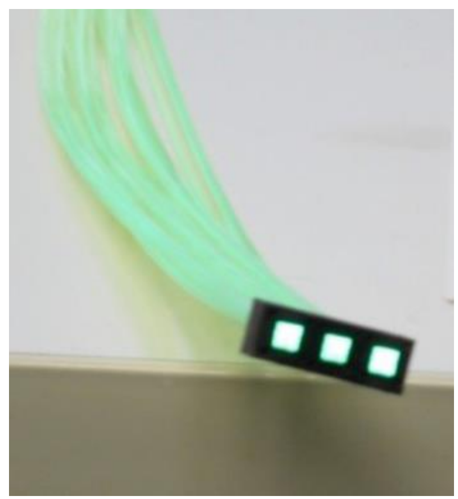
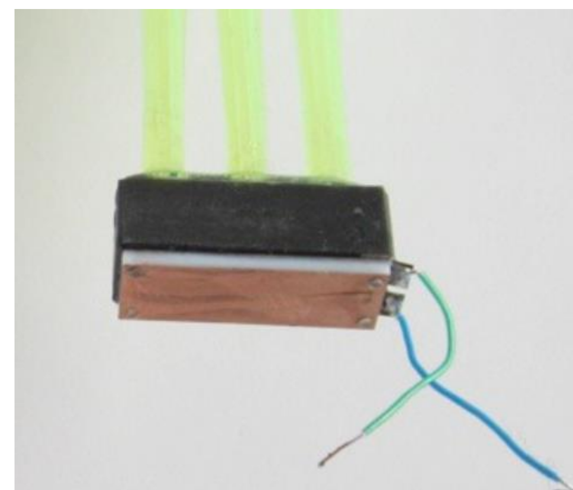
- Readout fibers with SiPMs
  - Ketek SiPMs in ‘die‘ → low background packaging
  - work at cryogenic temperatures
  - good QE, negligible Dark Rate





SiPM / fiber coupling

- 9 fibers coupled to 1 SiPM
- units of 27 fibers = 38 mm
- 3 SiPMs read out in parallel
- All in all:
  - 90 SiPMs
  - ~800m fiber

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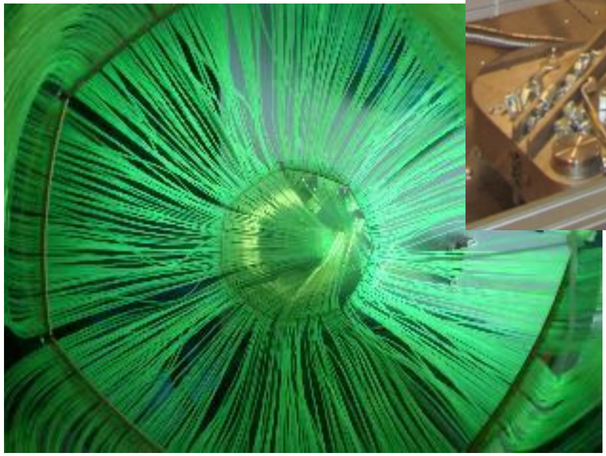


Instrumentation induced background

Background source		activity	Backgr. in ROI [cts/(keV kg yr)]	Backgr. after veto [cts/(keV kg yr)]
PMTs	^{228}Th	< 2.44 mBq/PMT	$< 3.1(1)*10^{-4}$	$< 3.1(5)*10^{-6}$
	^{226}Ra	< 2.84 mBq/PMT	$< 5.5(2)*10^{-5}$	$< 2.7(5)*10^{-6}$
cables	^{228}Th	< 14.4 µBq/m	$< 2.4(1)*10^{-4}$	$< 7.0(2)*10^{-6}$
	^{226}Ra	< 11.2 µBq/m	$< 3.9(1)*10^{-5}$	$< 5.5(2)*10^{-6}$
top & bottom shroud	^{228}Th	< 103 µBq/m^2	$< 2.7(1)*10^{-5}$	$< 9.9(5)*10^{-7}$
	^{226}Ra	< 282 µBq/m^2	$< 1.2(1)*10^{-5}$	$< 1.5(1)*10^{-6}$
fibers	^{228}Th	58 µBq/kg	$3.4*10^{-4}$	$6.4*10^{-8}$
	^{226}Ra	42 µBq/kg	$2.3*10^{-5}$	$6.3*10^{-7}$
total	^{228}Th		$< 9.2(1)*10^{-4}$	$< 1.1(1)*10^{-5}$
	^{226}Ra		$< 3.4(1)*10^{-4}$	$< 1.0(1)*10^{-5}$
	sum		$< 1.3(1)*10^{-3}$	$< 2.1(1)*10^{-5}$

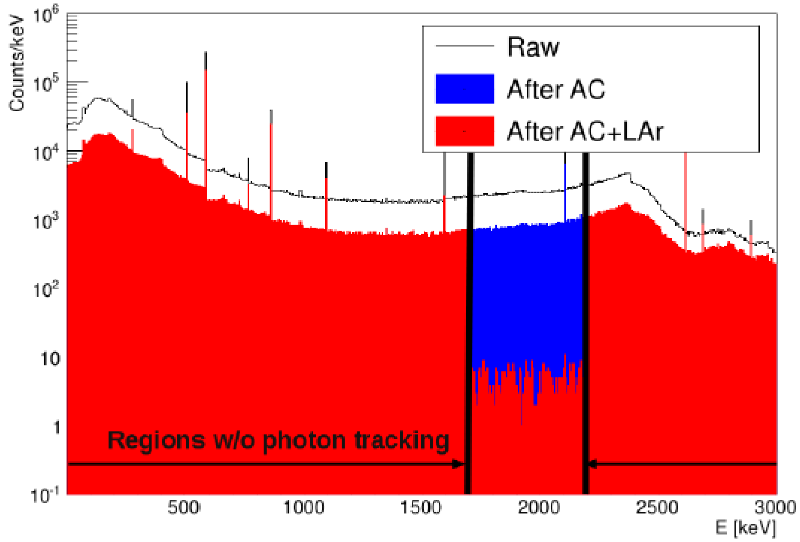
Conclusions / Outlook

- installation of LAr scintillation veto for Phase II
- deployment this year
- hybrid design (PMTs + fibers with SiPMs)
  - hardware tests
  - production ongoing
- promising suppression factors
  → significant reduction of background is possible
- low induced background index
- 1 ton test-stand ready to be used at TUM

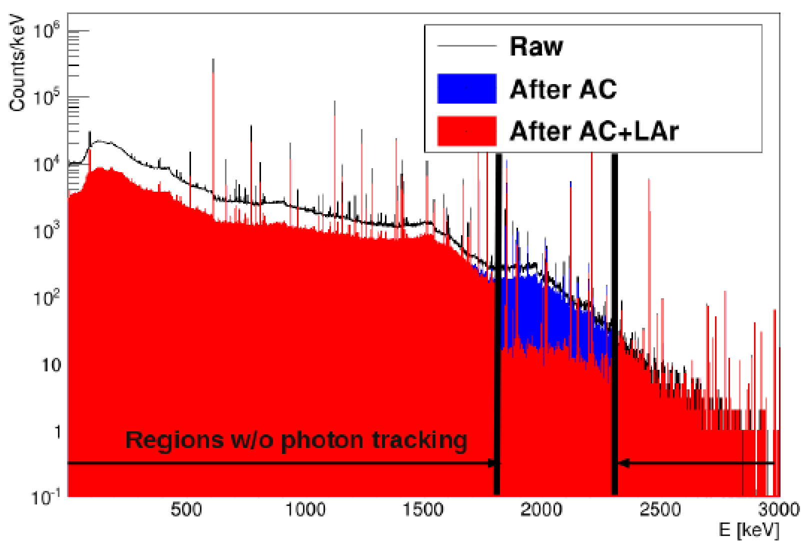
Backup: MC simulations

- veto efficiencies for different backgrounds by MC
- photon propagation in LAr if energy deposited in Ge detectors

^{208}Tl in holders:



^{214}Bi in holders:



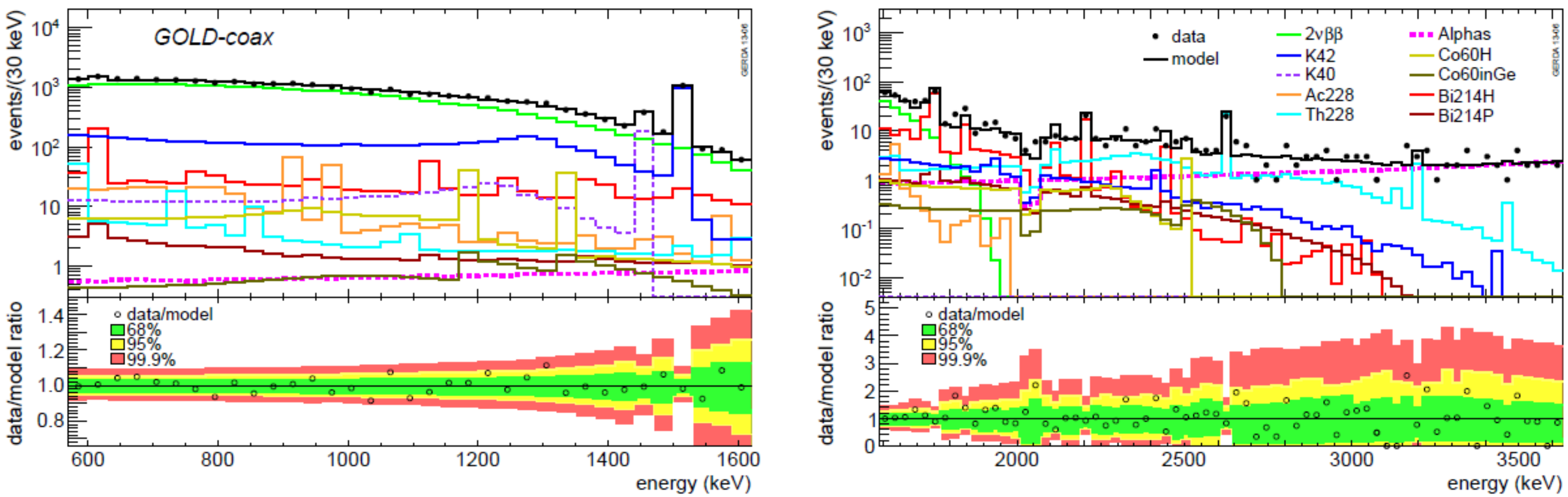
Backup: MC simulations

- veto efficiencies for different backgrounds by MC
- photon propagation in LAr if energy deposited in Ge detectors

- suppression factors:

	holders	surface	homogenous	external	detector
^{214}Bi	10.3 ± 0.3	3.5 ± 0.1	54.8 ± 7.9	-	-
^{208}Tl	320 ± 34	-	-	112.1 ± 38.8	-
^{60}Co	-	-	-	-	10*
^{42}K	-	1*	5.3 ± 0.6	-	-

Backup: Phase I Background



Ref. arXiv:1306.5084

- Phase I background for enriched coaxial detectors:

component	location	BI in $Q_{\beta\beta} \pm 5\,\mathrm{keV}$ $[10^{-3}\,\mathrm{cts/(keV\,kg\,yr)}]$	relative contribution
total		18.5	
^{42}K	LAr homogenous	3.0	16.2 %
^{60}Co	det. assembly	1.4	7.6 %
^{60}Co	germanium	0.6	3.2 %
^{214}Bi	det. assembly	5.2	28.1 %
^{214}Bi	p^+ surface	1.4	7.6 %
^{228}Th	det. assembly	4.5	24.3 %
α model	p^+ surface	2.4	13.0 %

… other GERDA talks:

- “GERDA and the search for neutrinoless double beta decay: first results and perspectives” – W. Maneschg, T65.1, Dienstag, 25. März 2014, 16:45–17:05, P106
- “Performance test of the GERDA Phase II detector assembly” – T. Bode, T105.1, Donnerstag, 27. März 2014, 16:45–17:00, P7
- “Dead layer and active volume determination of enriched BEGe detectors for the GERDA experiment” – R. Falkenstein, T105.5, Donnerstag, 27. März 2014, 17:45–18:00, P7
- “Study of the double beta decay of 76Ge into excited states of 76Se” – T. Wester , T65.3, Dienstag, 25. März 2014, 17:20–17:35, P106
- “Pulse shape studies with ultra high purity point contact detectors” – A. Hegai, T18.1, Montag, 24. März 2014, 11:00–11:15, P106
- “42K background mitigation for GERDA Phase II” – A. Lubashevskiy, T65.4, Dienstag, 25. März 2014, 17:35–17:50, P106
- “Normalization procedure of Pulse Shape Discrimination for Broad Energy Germanium Detector” – Heng-Ye Liao, T105.4, Donnerstag, 27. März 2014, 17:30–17:45, P7
- “Setup for an in-situ measurement of the total light extinction of liquid argon in GERDA” – B. Schneider, T65.2, Dienstag, 25. März 2014, 17:05–17:20, P106