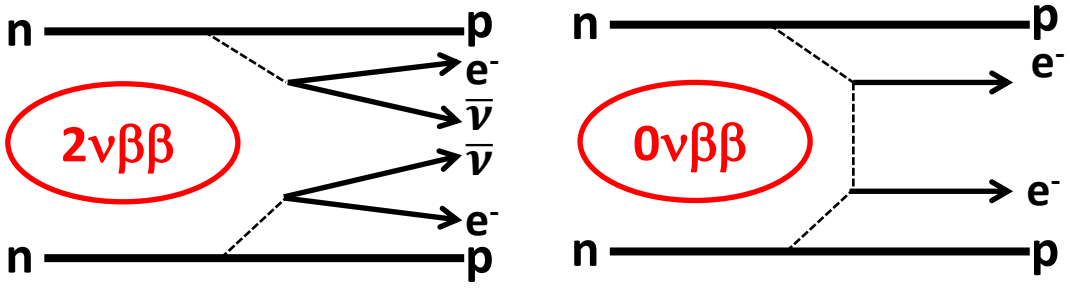
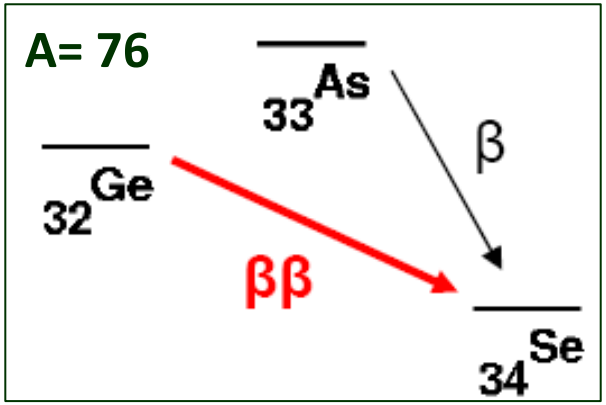
Status of preparations for the Phase II of the GERDA experiment aimed for the 0νββ decay search

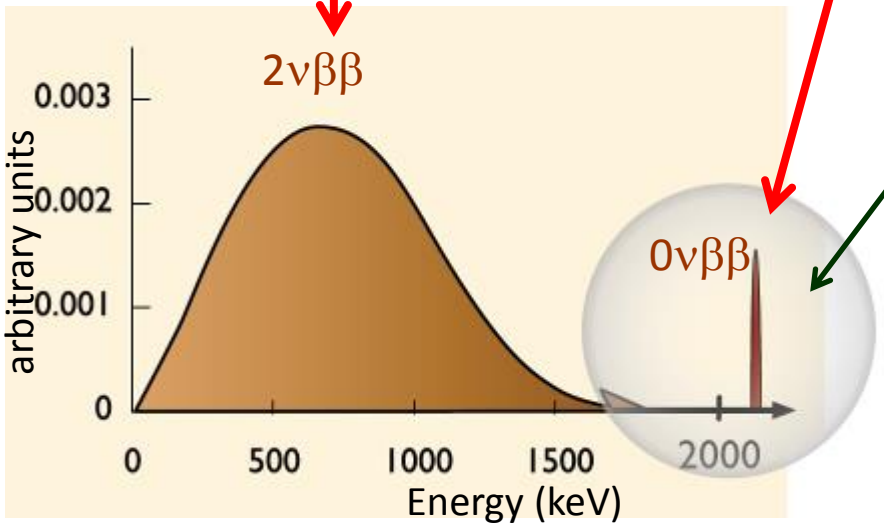
A.V. Lubashevskiy
for the GERDA collaboration,
Max-Planck-Institut für Kernphysik,
Heidelberg, Germany.

Motivation

Search for the neutrinoless double beta ($0\nu\beta\beta$) decay is a good way to search for the physics beyond the Standard Model. The observation of such a decay would prove that lepton number is not conserved.







Region of interest (ROI) of $0\nu\beta\beta$

Searching for $0\nu\beta\beta$ helps to understand:

- Nature of ν (Dirac or Majorana)
- Neutrino mass scale
- Neutrino hierarchy
- Some fields in particle physics including cosmology

^{76}Ge 0νββ decay

The GERDA experiment is a low background experiment aimed to search for ^{76}Ge 0νββ decay.

Experimental sensitivity:

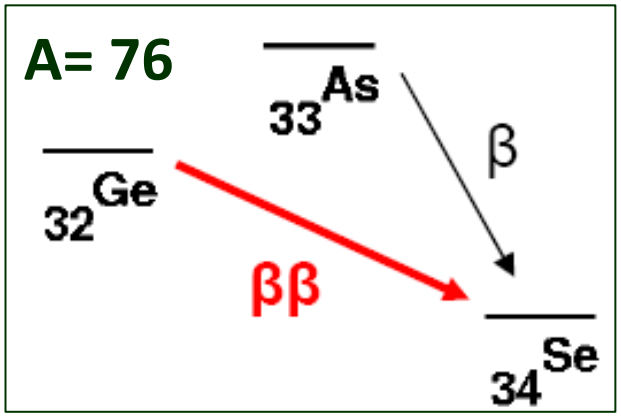
If background >> 1

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot a \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot BI}}$$

If background << 1

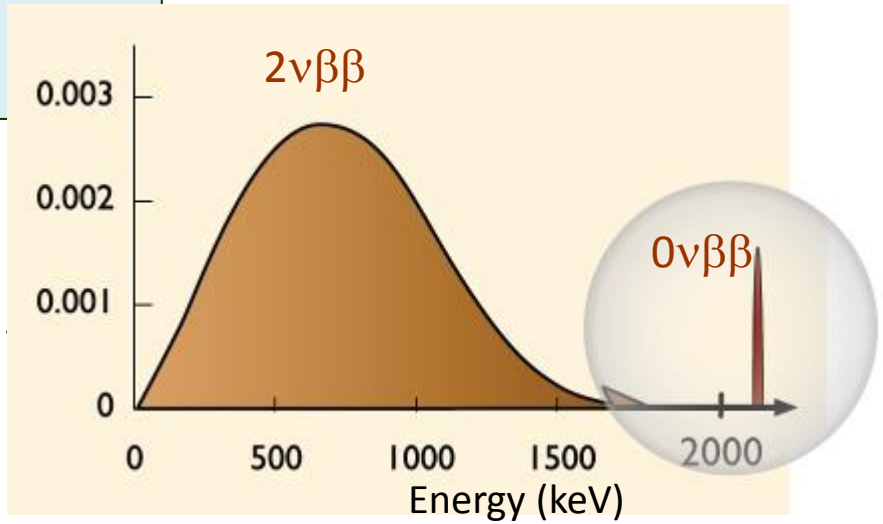
$$T_{1/2}^{0\nu} \propto \varepsilon \cdot a \cdot M \cdot t$$

ε Efficiency
M·t Mass·Time = Exposure
a Abundance
ΔE Energy resolution
BI Background Index



Search with enriched HPGe detectors enriched with ^{76}Ge:

- Detector = source
- Very good detector's energy resolution: better than 0.2%
- Intrinsically pure material



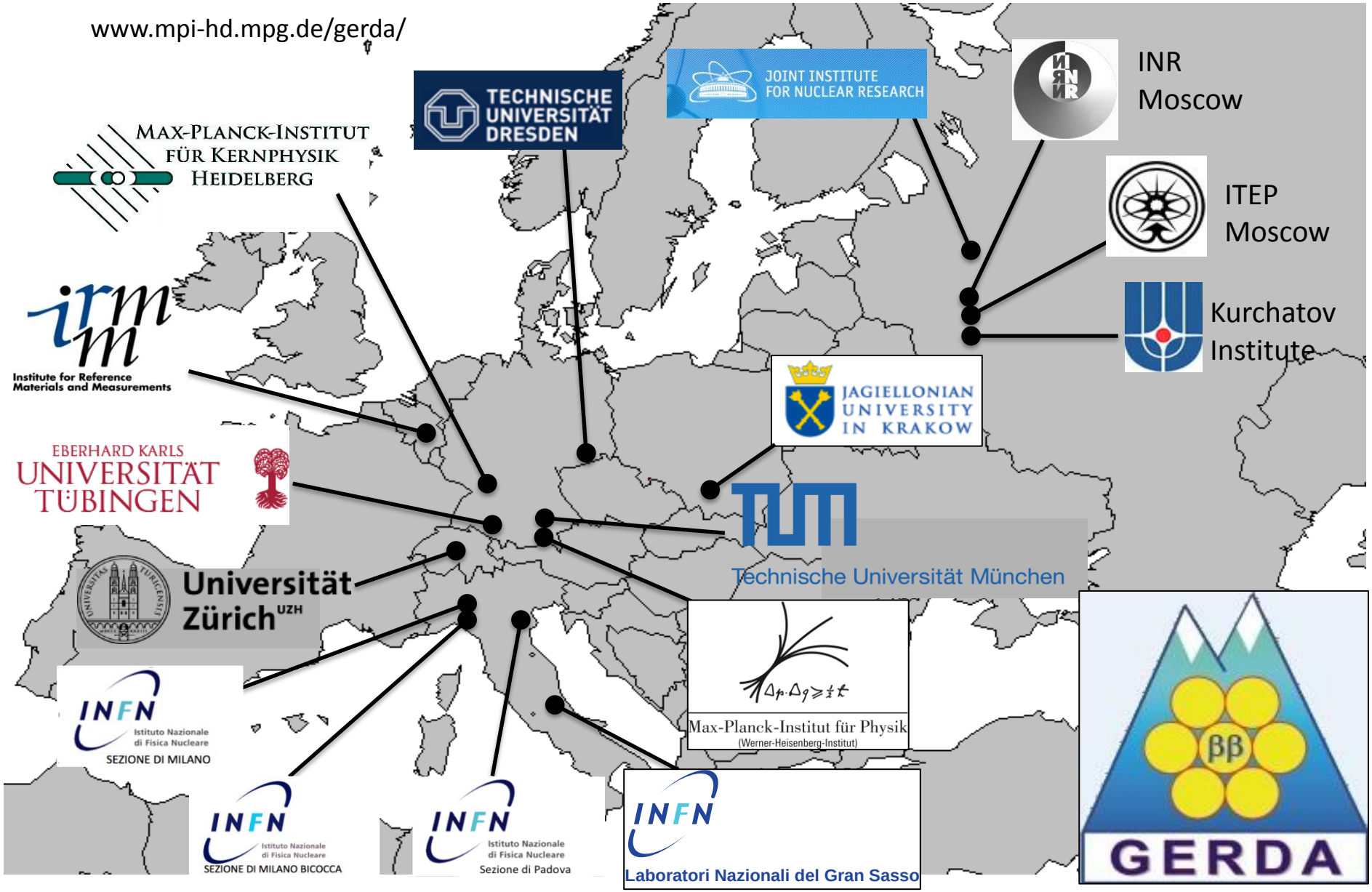
GERDA collaboration

GERDA collaboration meeting in Heidelberg, 2014

6 countries, 16 institutions, 132 members

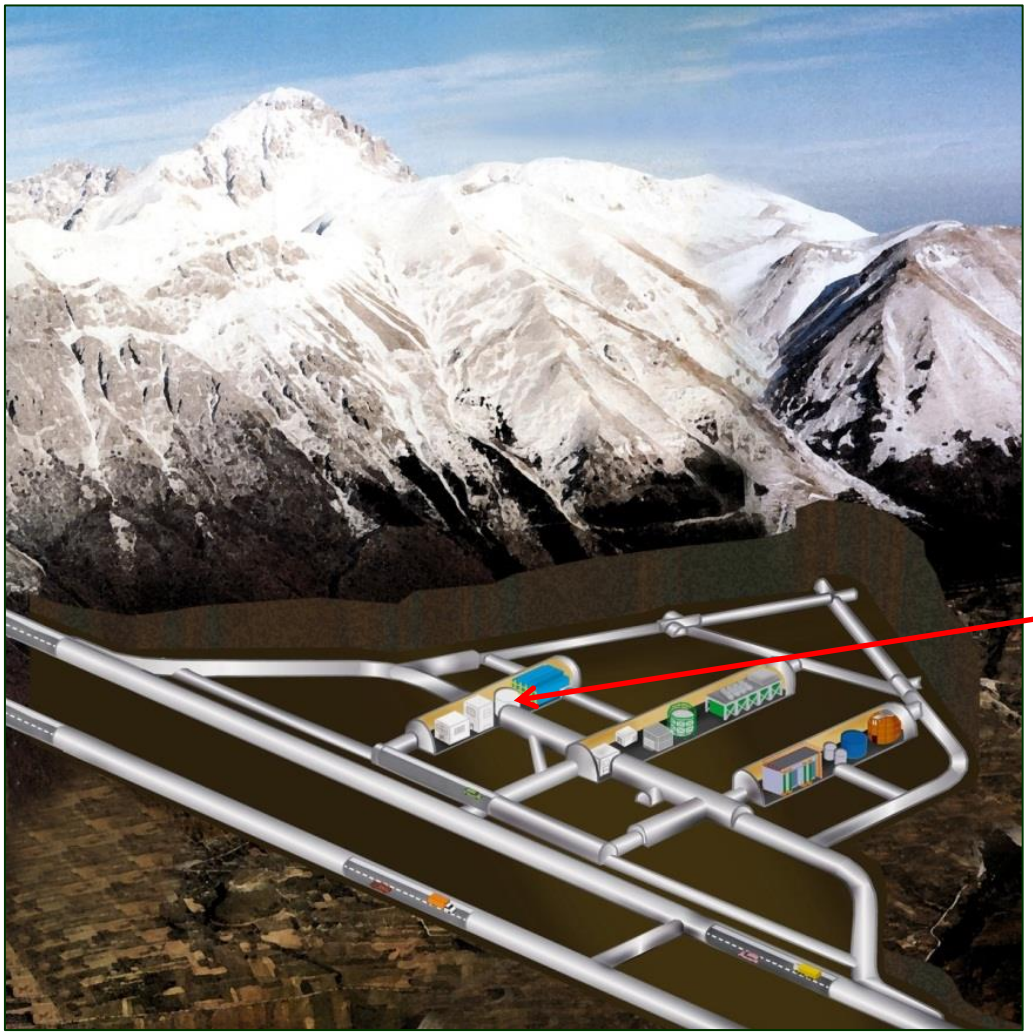
GERDA collaboration

www.mpi-hd.mpg.de/gerda/

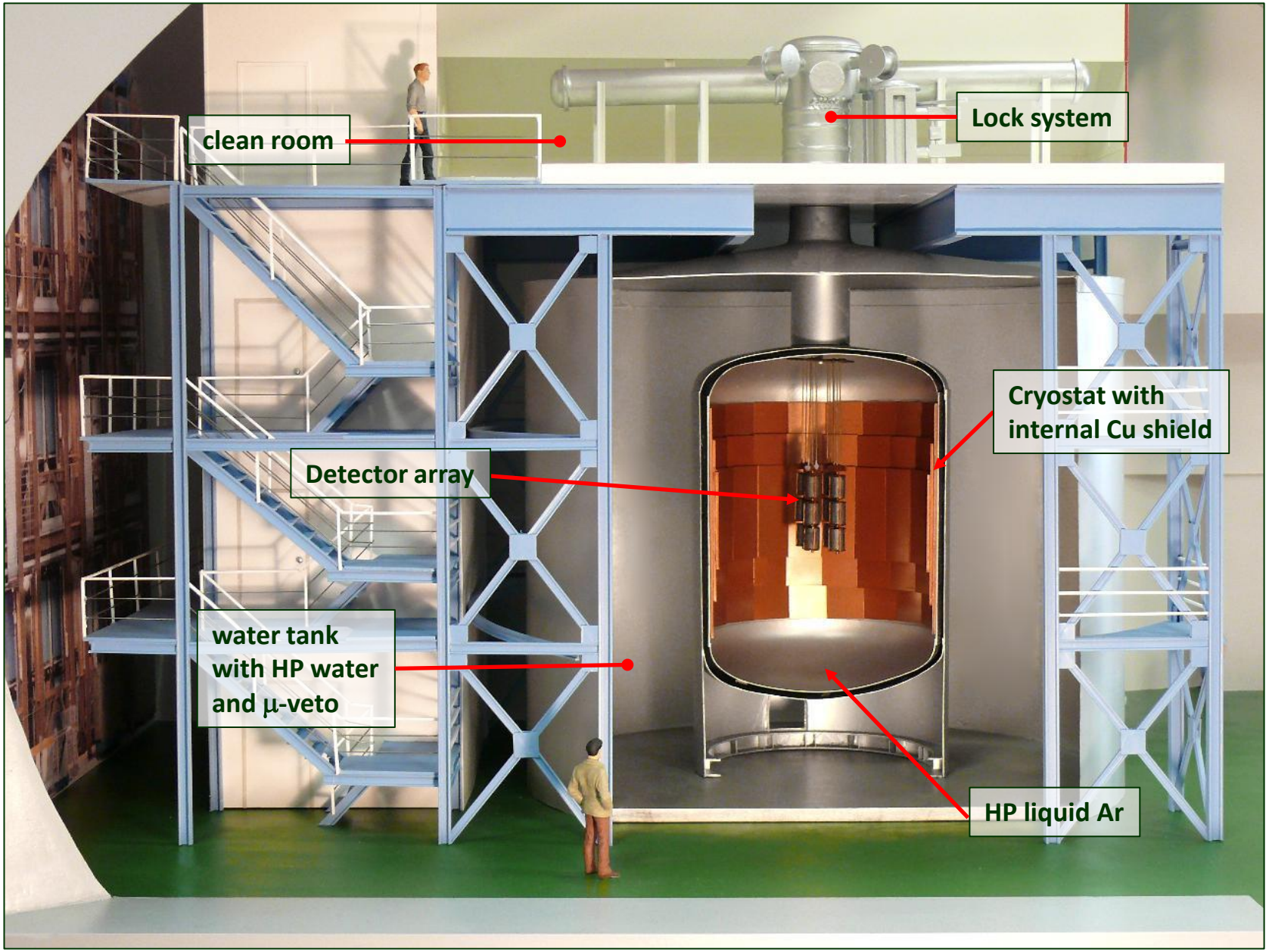


Background reduction

GERDA experimental setup located at LNGS underground laboratory of INFN (Italy). The rock overburden is equivalent to 3500 m w.e. This allows to reduce μ (~ 10^6 times) and neutron flux induced by cosmic radiation.

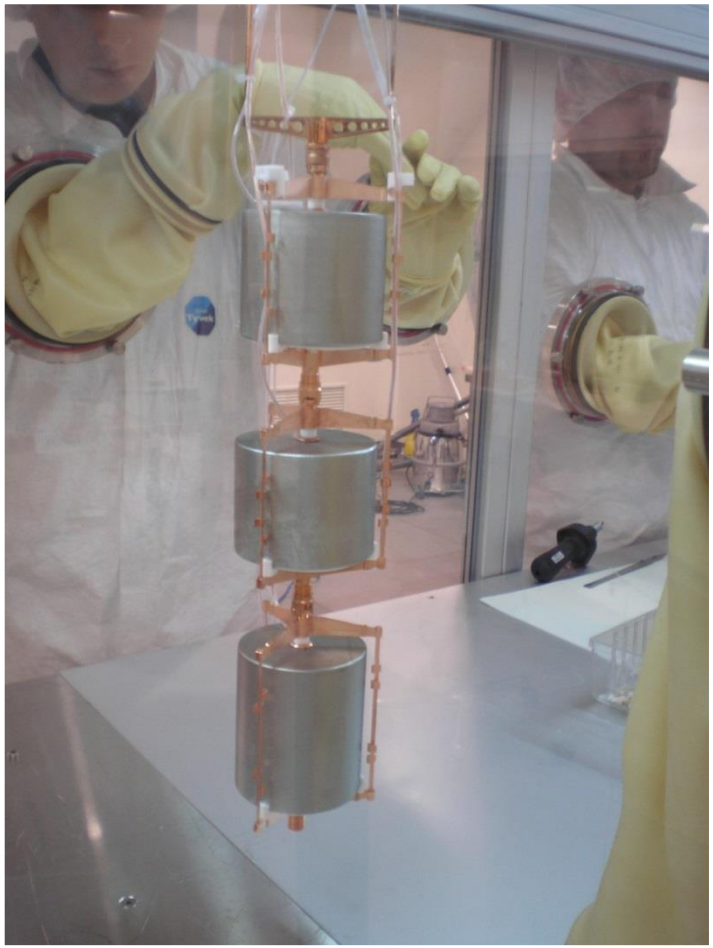


Scheme of GERDA experiment



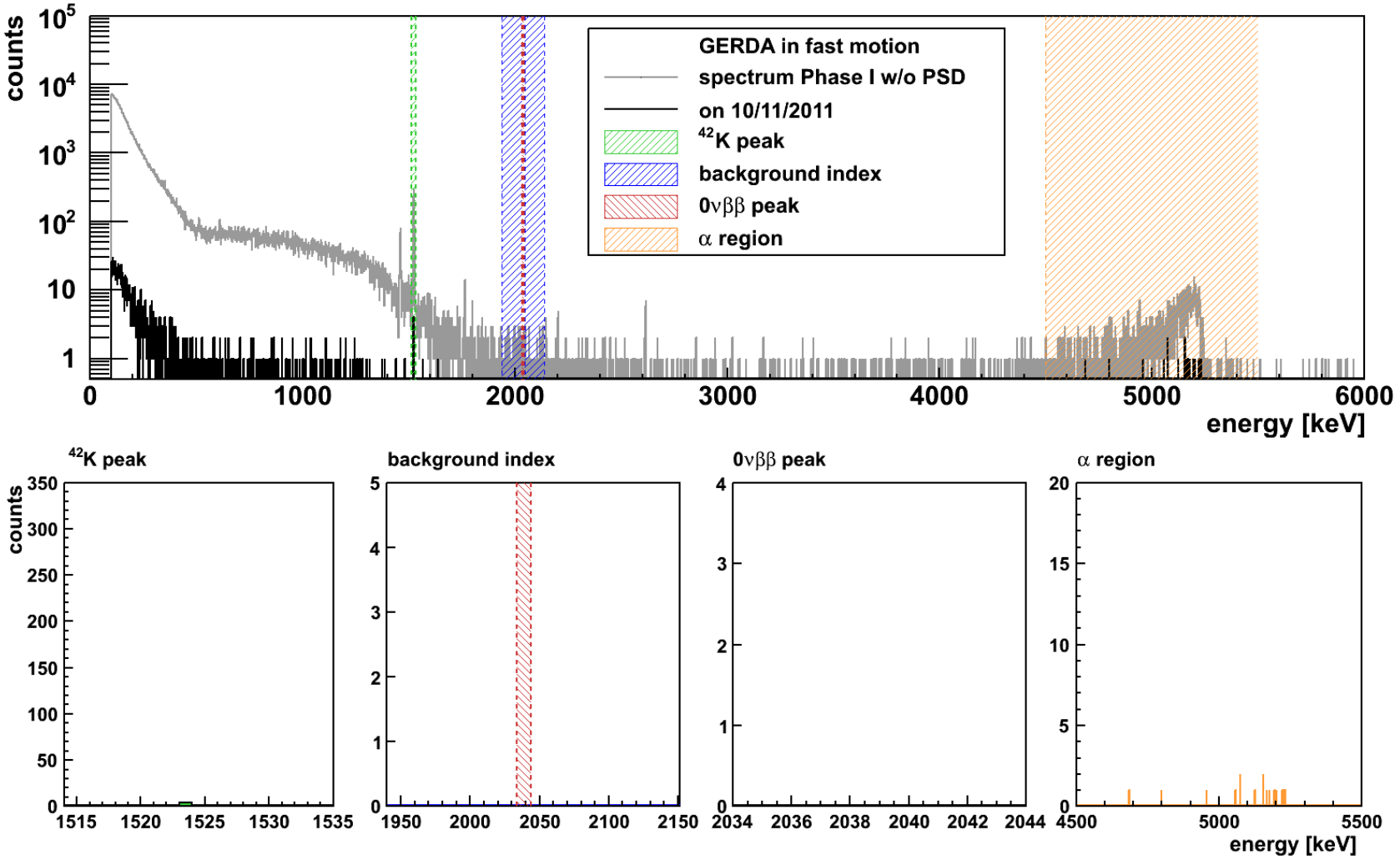
General concept

Bare Ge detectors submerged into liquid argon (LAr) allows to decrease background from the surrounding materials. Liquid argon shields from the radiation and cools down the Ge detectors.



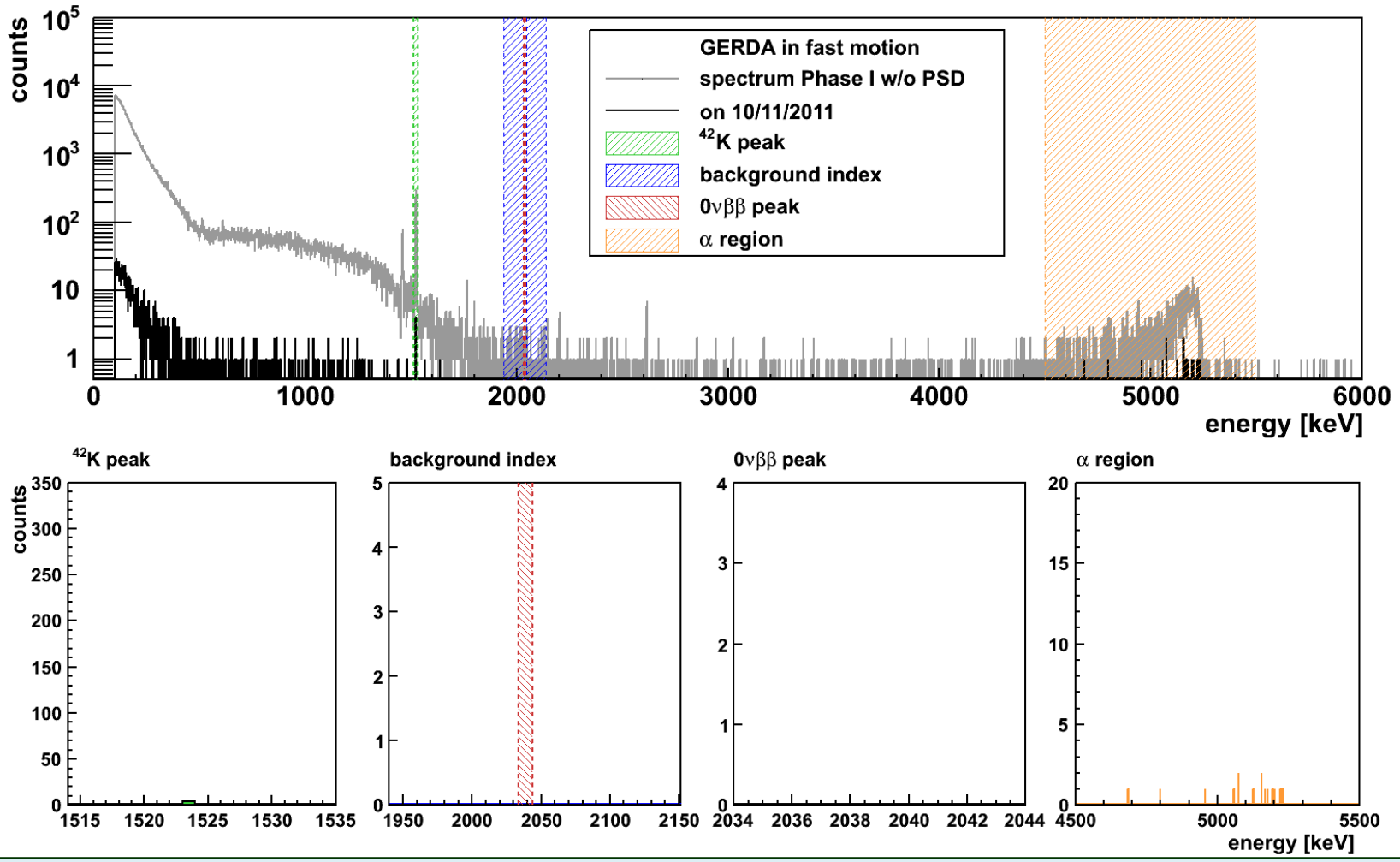
~ 80 g Cu,
~ 10 g PTFE,
~ 1 g Si per detector (in Phase I)

GERDA Phase I



- **8 enriched Coaxial detectors: working mass 14.6 kg. Average FWHM at $Q_{\beta\beta}$: ΔE = 4.8 keV**
- **Natural Ge: 3.0 kg.**
- **5 enriched BEGe: working mass 3.0 kg (for test Phase II concept): ΔE = 3.2 keV**

GERDA Phase I

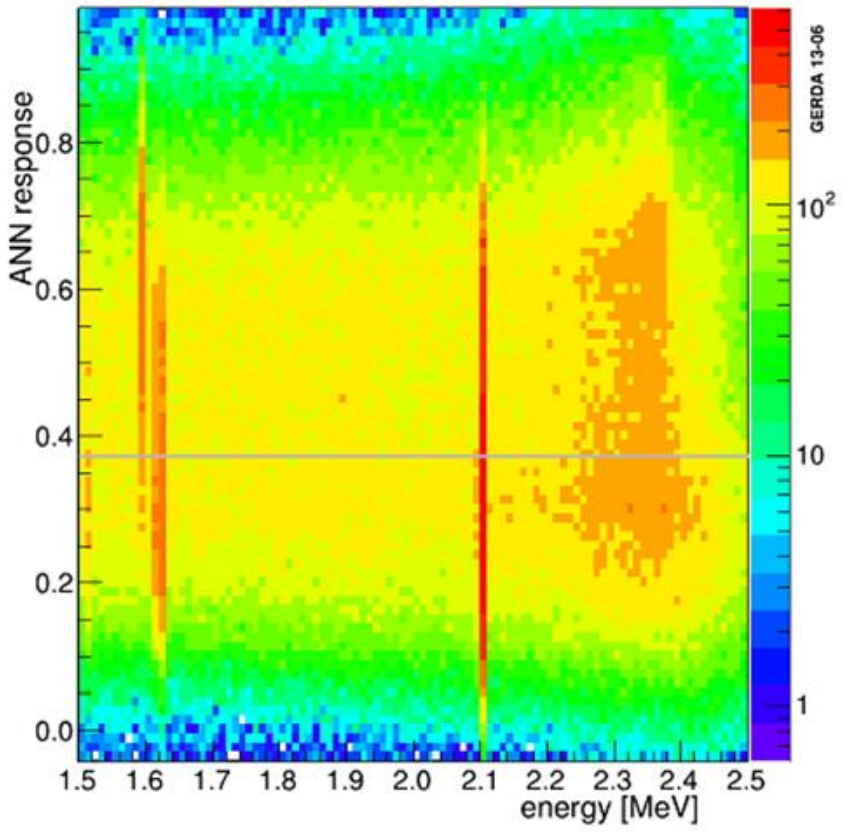


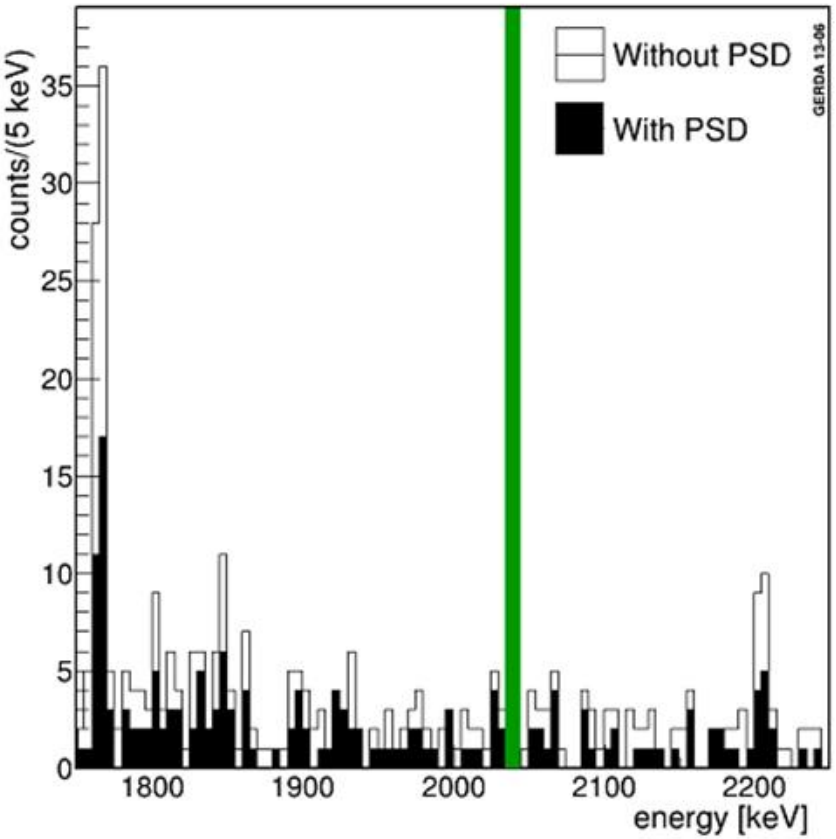
- Achieved Background Index (BI) for semi-coaxial detectors is **0.018(2) cts/(keV·kg·yr).**
- BI after pulse shape discrimination: **0.011(2) cts/(keV·kg·yr).**
- About **one order of magnitude better** than in previous experiments with HPGe detectors.

GERDA Phase I

PSD analysis of semi-coaxial detectors was performed with help of artificial neuron network. Response of the PSD analysis versus energy for events from ^{228}Th calibrations.

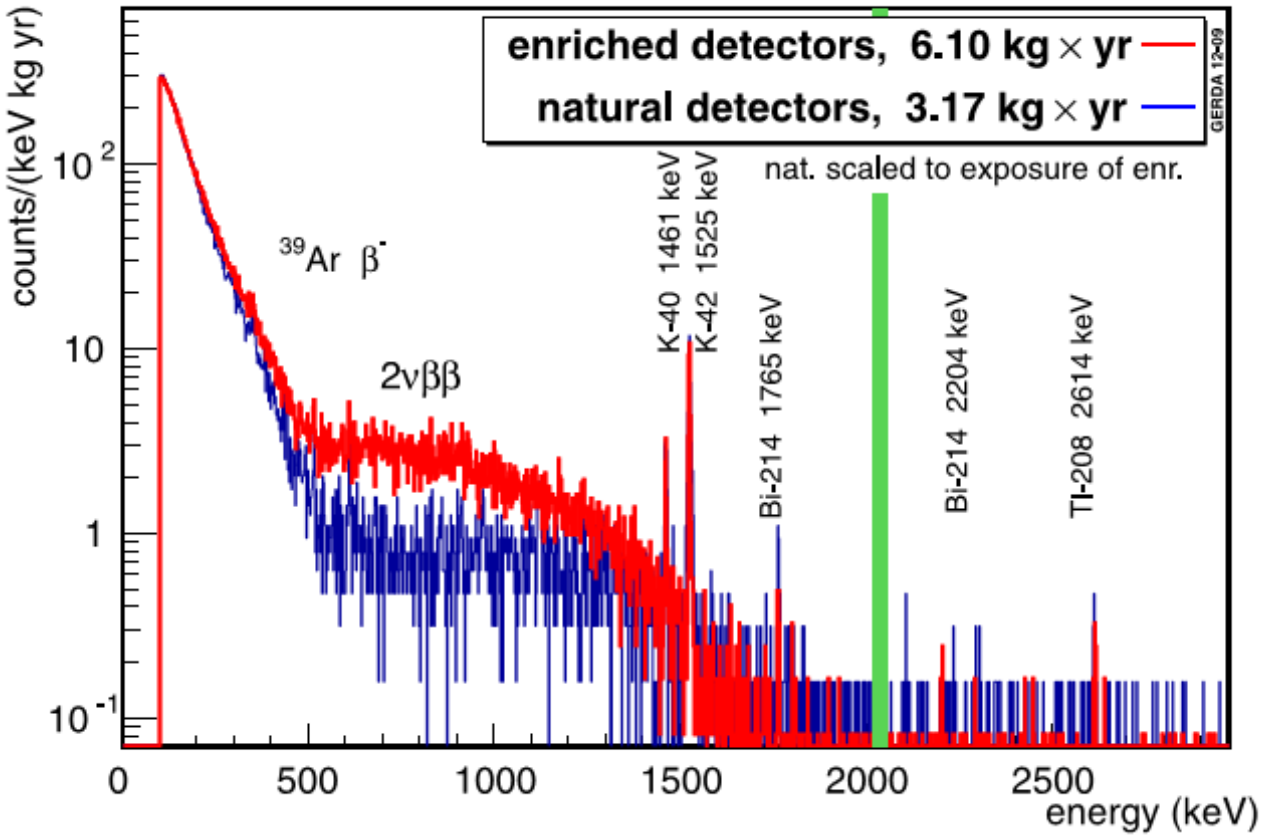
Energy spectrum from semi-coaxial detectors before and after the PSD selection.





Blinded region

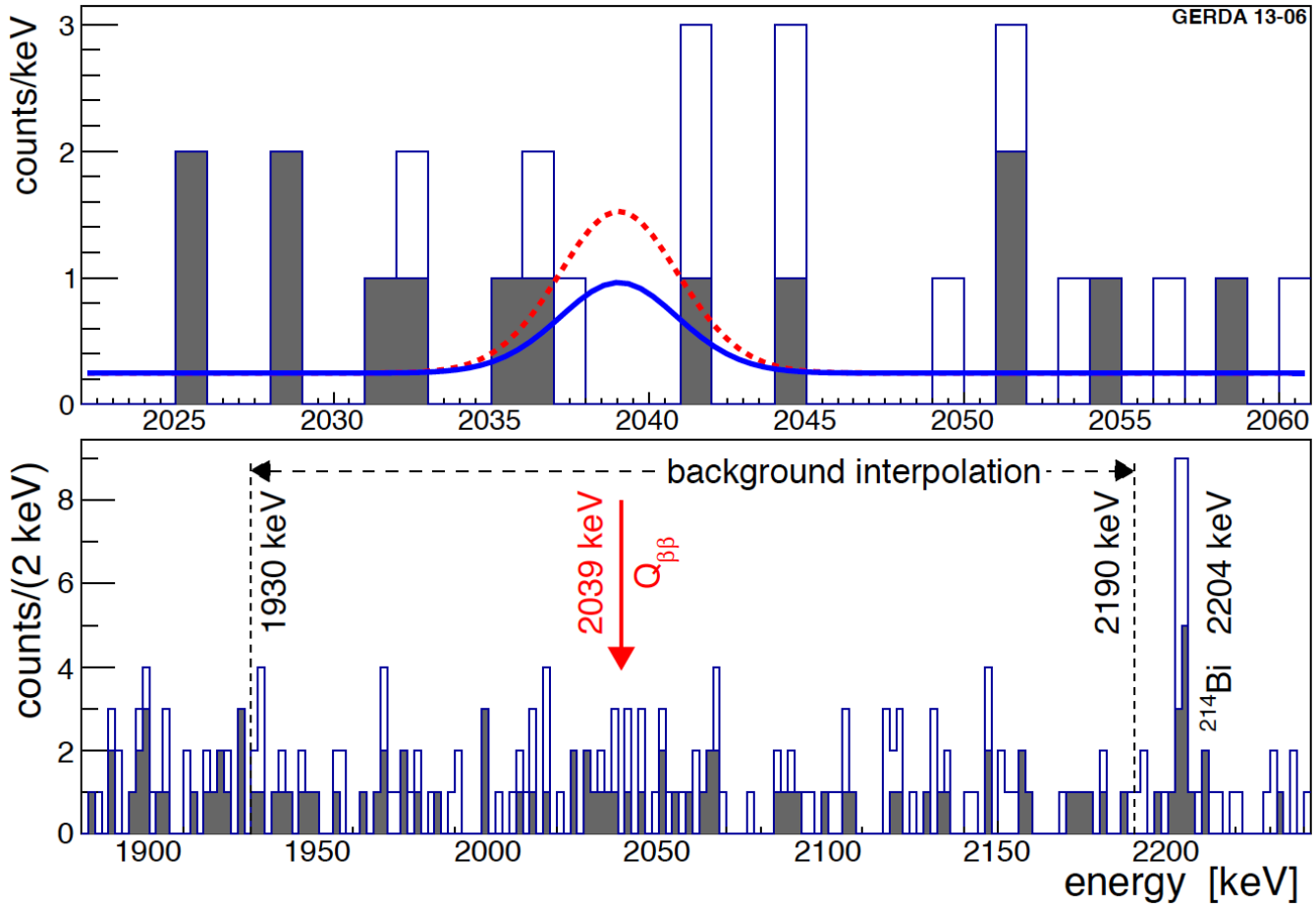
During data taking we blinded energy region between 2019 keV – 2059 keV!



Total accumulated exposure is **21.6 kg·yr.**
After fixating of all analysis parameters we opened blinded region.

GERDA Phase I results

Energy spectrum from all enriched Ge detectors with and without the PSD selection.



PSD	Dataset	Obs.	Exp. bkg
no	Golden	5	3.3
	Silver	1	0.8
	BEGe	1	1.0
yes	Golden	2	2.0
	Silver	1	0.4
	BEGe	0	0.1

No event remain within $Q_{bb} \pm \sigma$ after PSD cut.
Best fit $N^{0\nu} = 0$

The **"claim"** of a signal for $0\nu\beta\beta$ decay of ^{76}Ge is **ruled out** by GERDA with **99%** probability.

GERDA: 90% lower limit ($T_{1/2}^{0\nu}$) [Phys. Rev. Lett. 111 (2013) 122503]

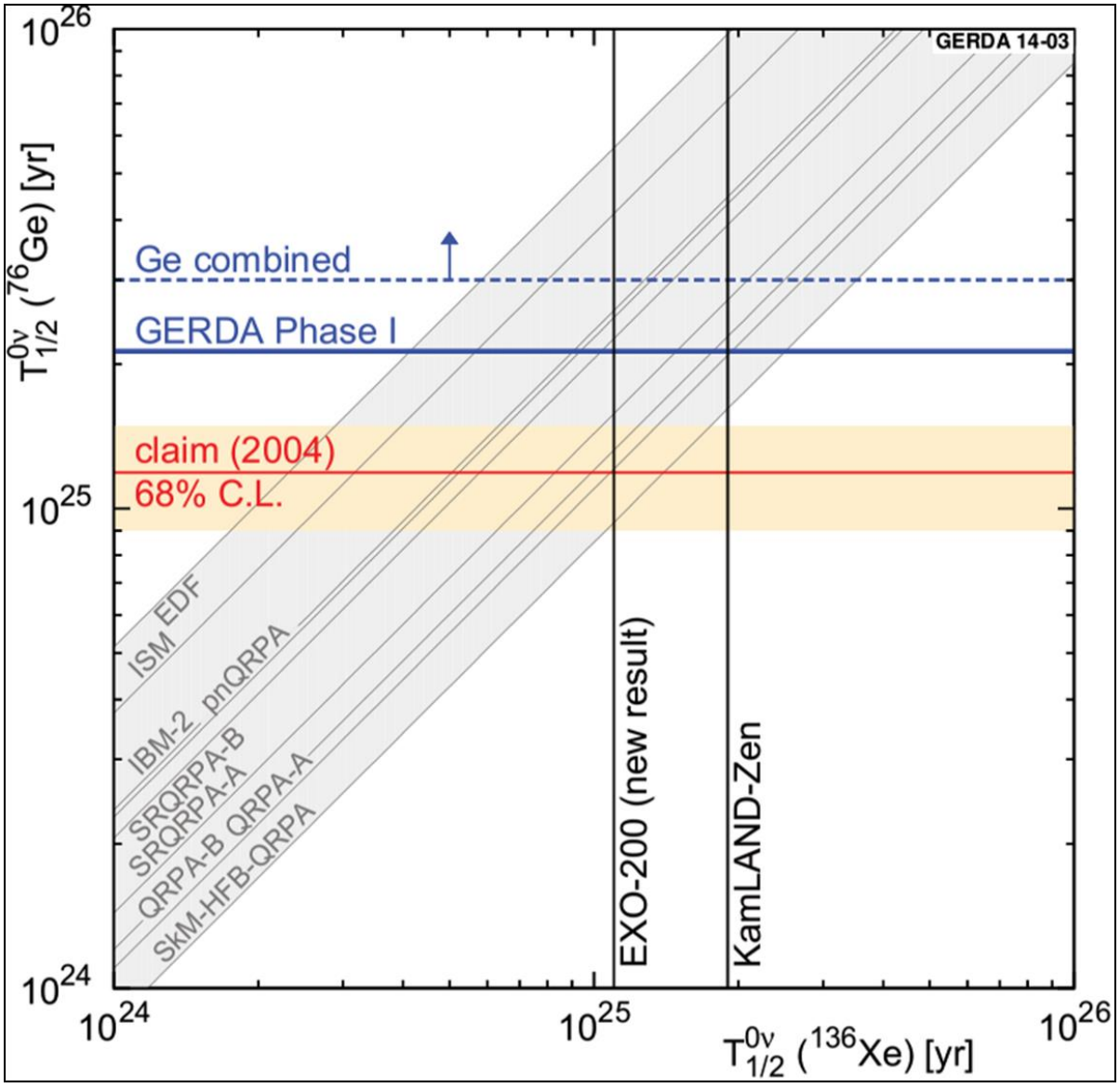
Claim: $T_{1/2}^{0\nu} = 1.19 \times 10^{25}$ (Phys. Lett. B 586 198 (2004))

The limit on the half-life of $0\nu\beta\beta$ decay is:

$$T_{1/2}^{0\nu} > 2.1 \cdot 10^{25}\ yr$$

GERDA Phase I results

90% C.L. on $T_{1/2}$ for ^{76}Ge and ^{136}Xe compared with the signal claim.



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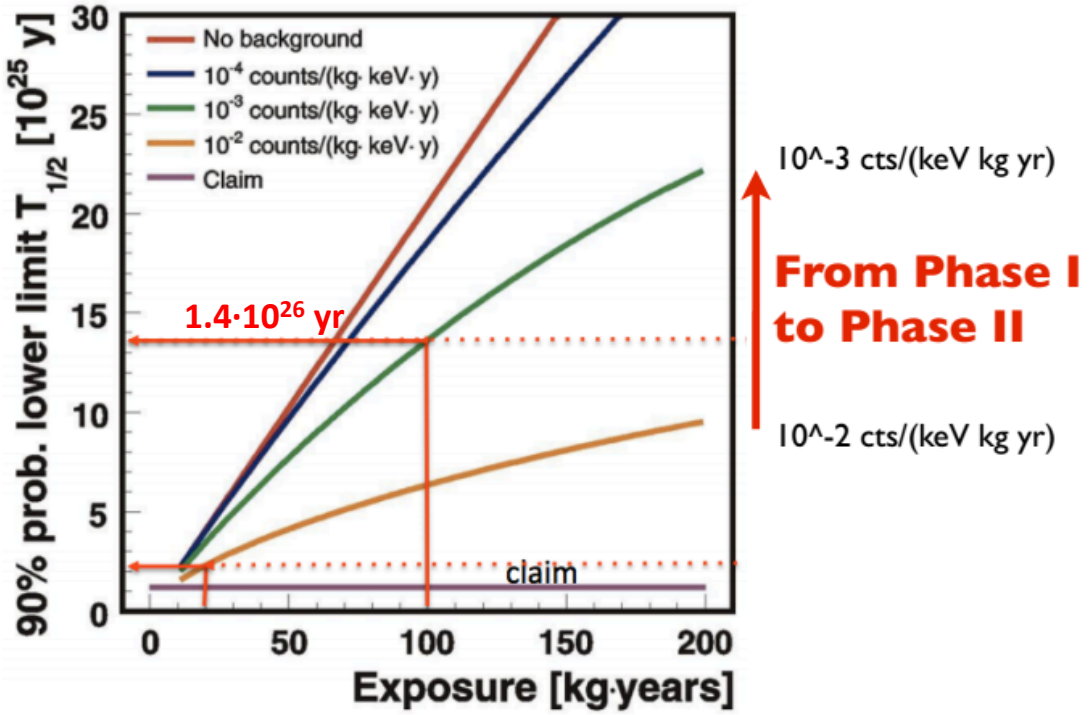
The limit on the half-life of $0\nu\beta\beta$ decay is:

$$T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}\ yr$$

From Phase I to Phase II

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot a \cdot M \cdot t$$

$$T_{1/2}^{0\nu} \propto \varepsilon \cdot a \cdot \sqrt{\frac{M \cdot t}{\Delta E \cdot BI}}$$

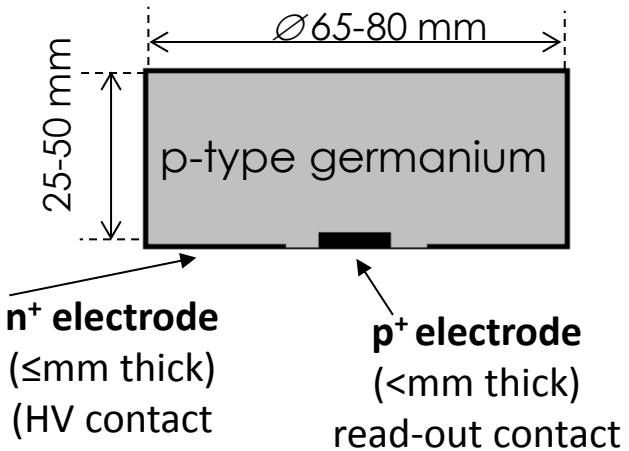


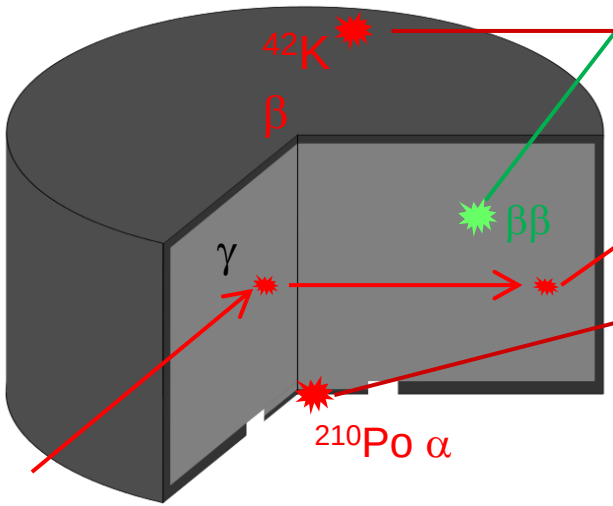
- Increase mass: additional 30 new BEGe detectors with total mass of ~ 20 kg.
- Exposure: 20 kg yr → 100 kg yr (within 3 years).
- Reduce background: (from **10^{-2} cts/(keV kg yr)** → **10^{-3} cts/(keV kg yr)**):
  - ✓ Power Pulse Shape Discrimination (PSD) of new BEGe detectors.
  - ✓ LAr light scintillation veto.
  - ✓ Cleaner materials.

GERDA Phase II preparations

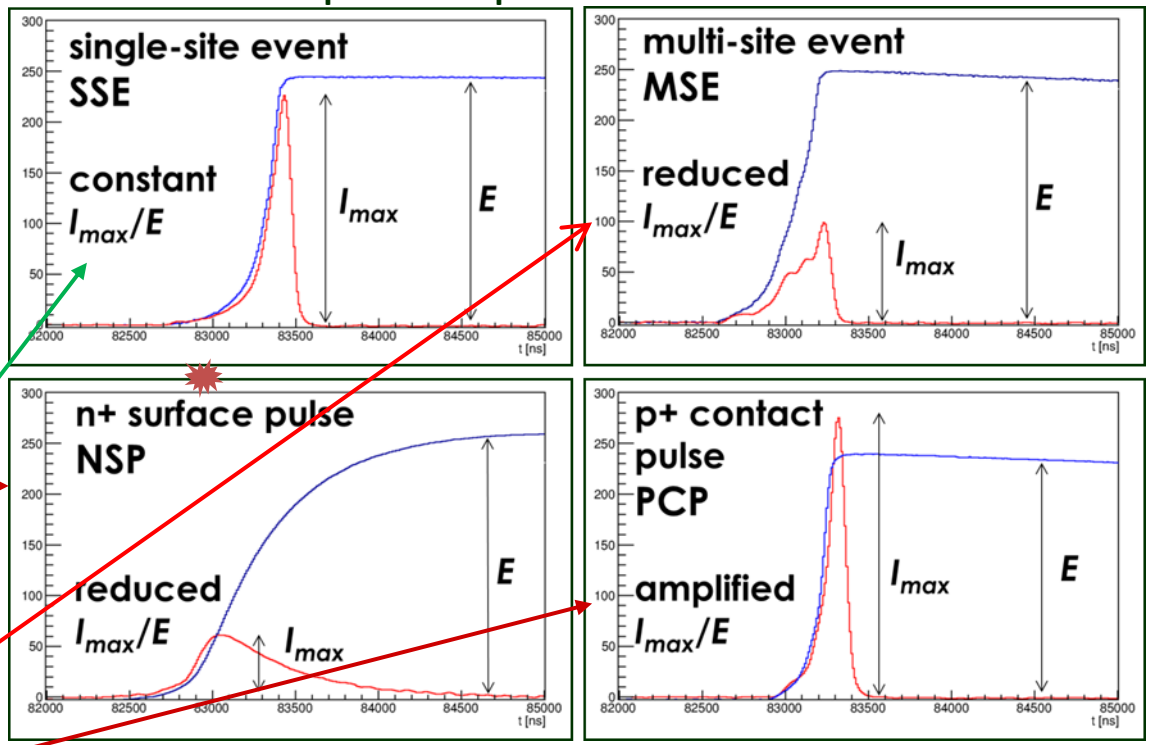
New BEGe detectors for GERDA Phase II:

- Better energy resolution (FWHM up to 1.6 keV@1.3MeV in a vacuum cryostat).
- Powerful PSD.
- Holders with lower intrinsic radioactivity.



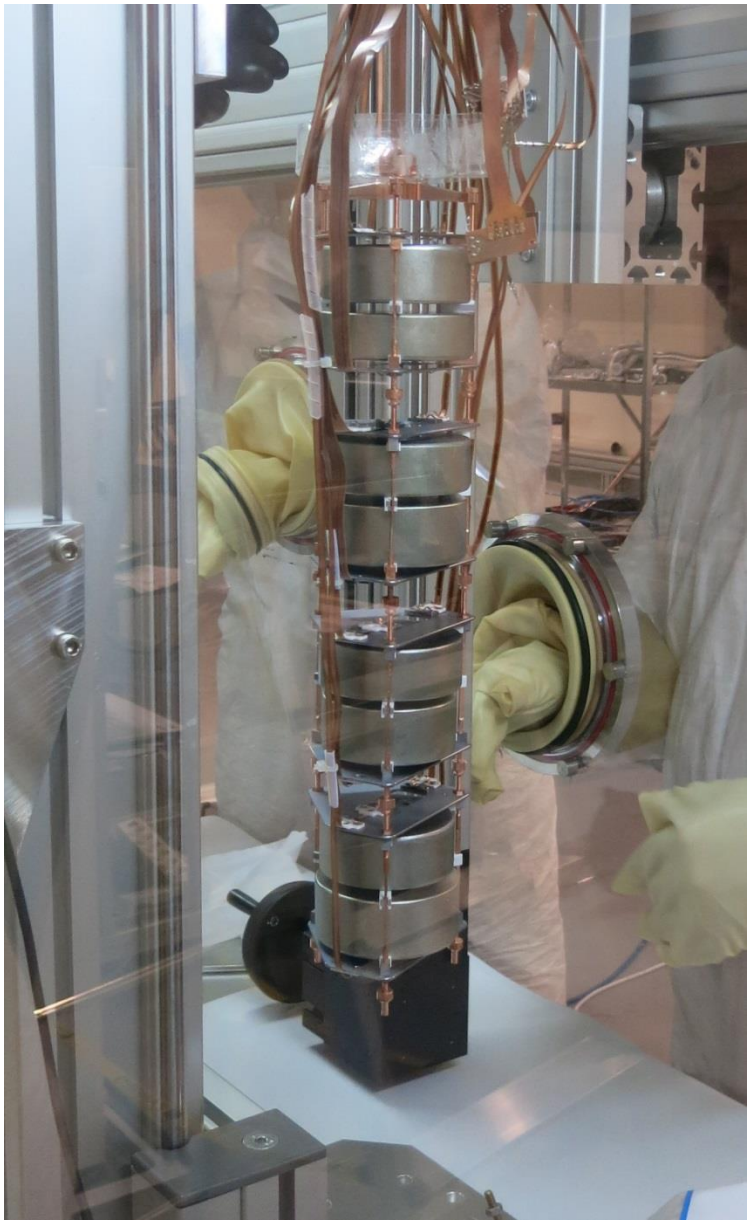


Examples of the pulses from BEGe detector.



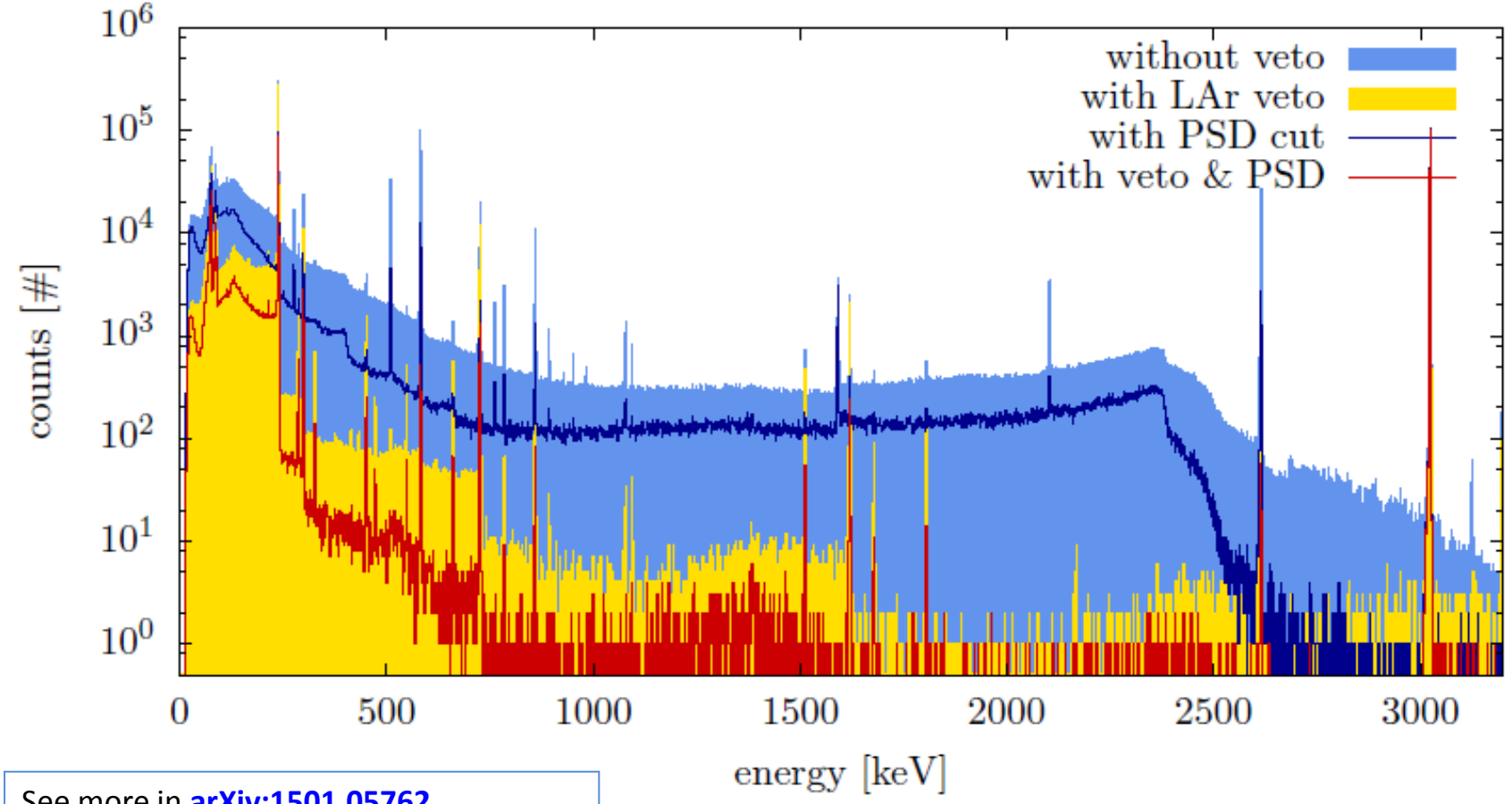
All detectors prepared and ready for installation in GERDA.

GERDA Phase II preparations



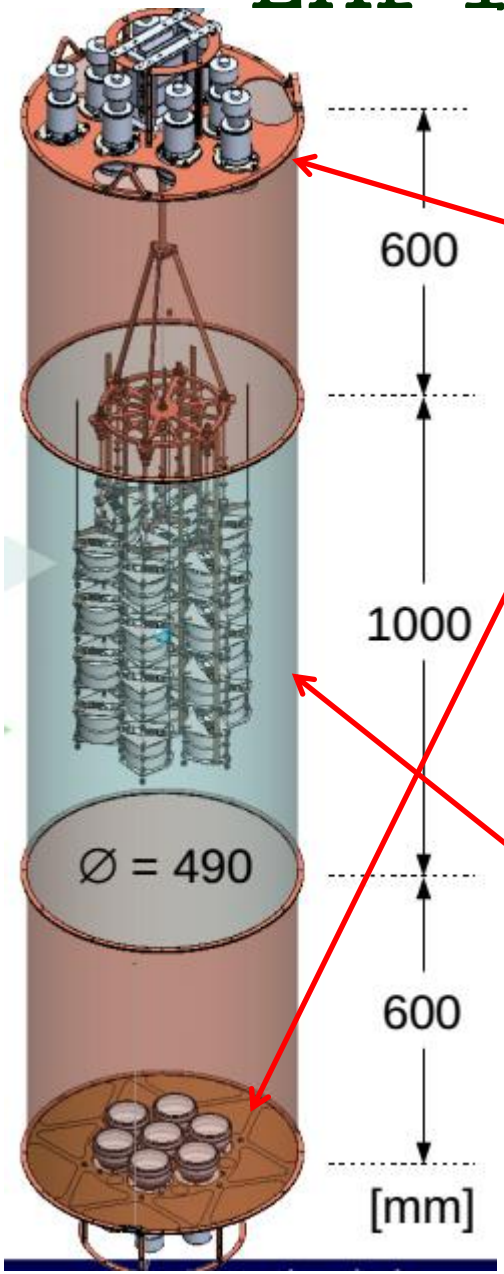
LAr light instrumentation

Measurements with BEGe detector inside LArGe test facility show very good suppression of background. For ^{228}Th inner source the suppression factor > 5000 has been obtained after applying LAr veto and PSD (but for other sources it can be lower for example for external ^{226}Ra it is only factor 18). That is why to reach goal of Phase II background index of < 10^{-3} cts/(keV·kg·yr) light scintillation veto is implemented in GERDA experiment.



See more in [arXiv:1501.05762]

LAr light instrumentation



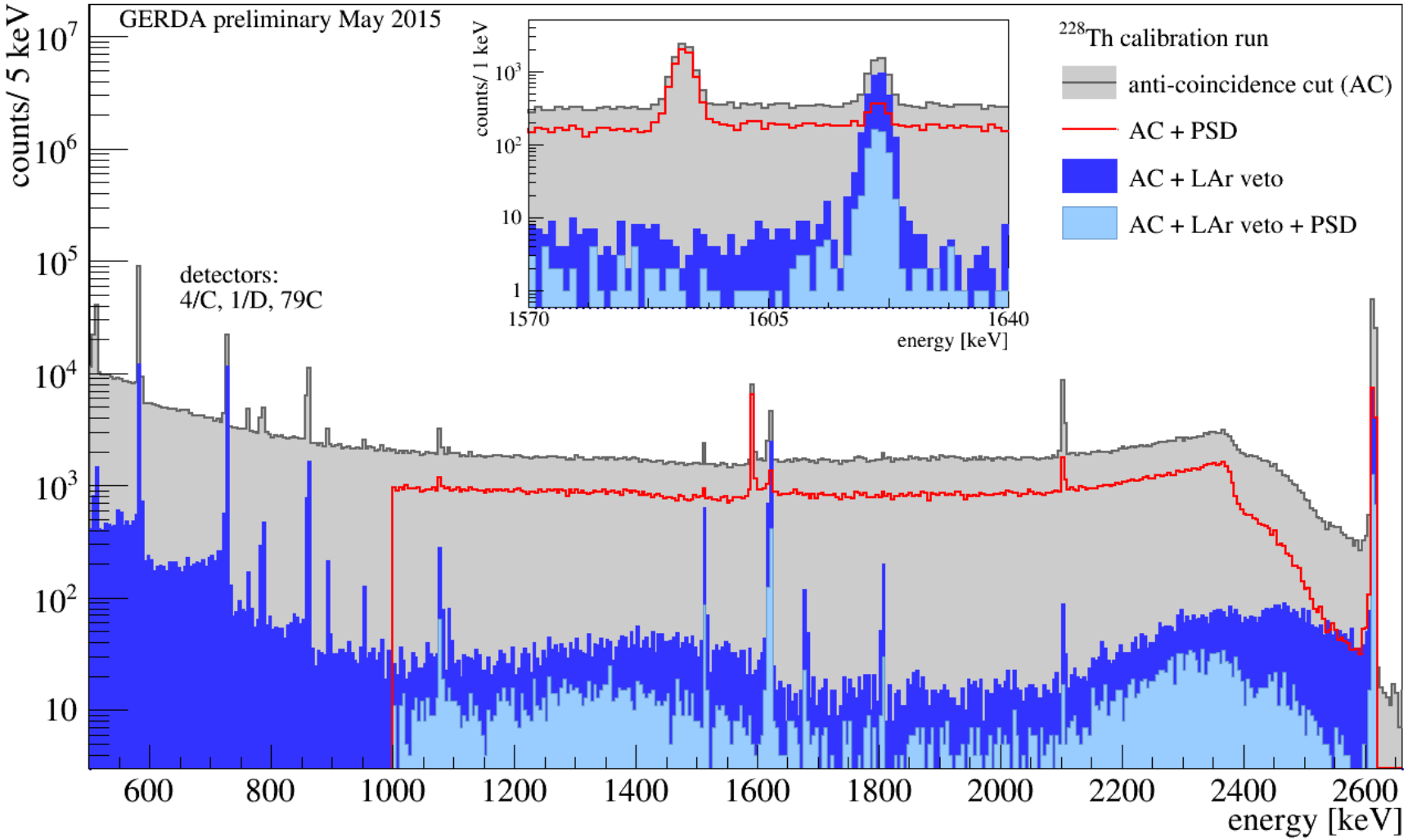
PMTs readout consist of 16 3" PMTs

Scintillation fibers and SiPM readout

LAr light instrumentation

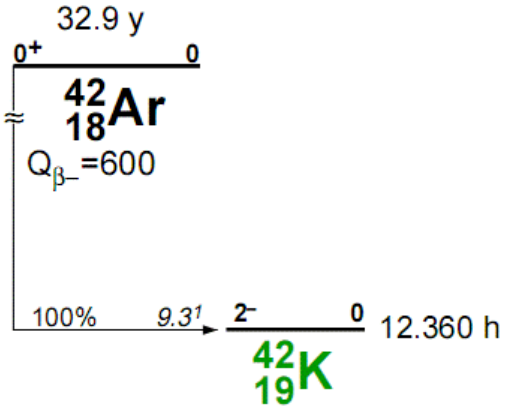
LAr light instrumentation was developed and successfully installed in GERDA.

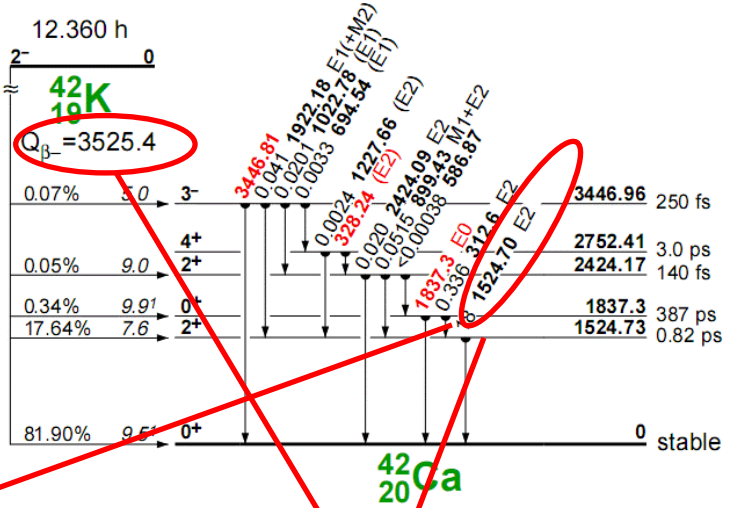
First commissioning tests

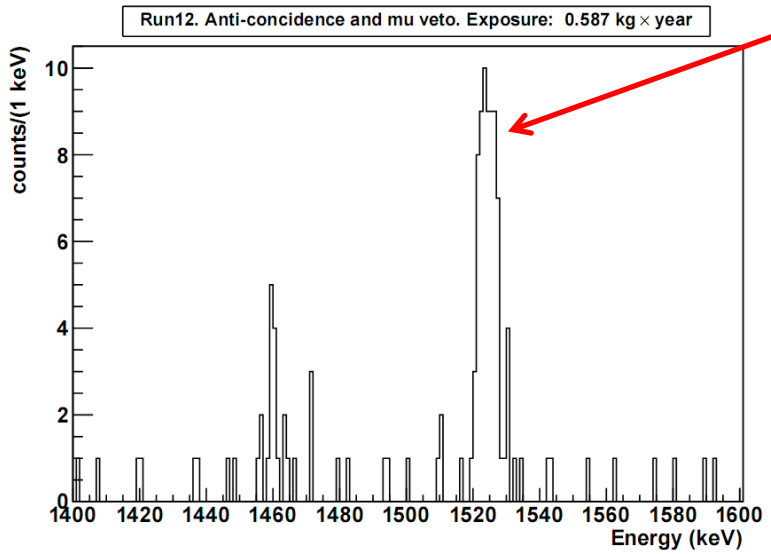


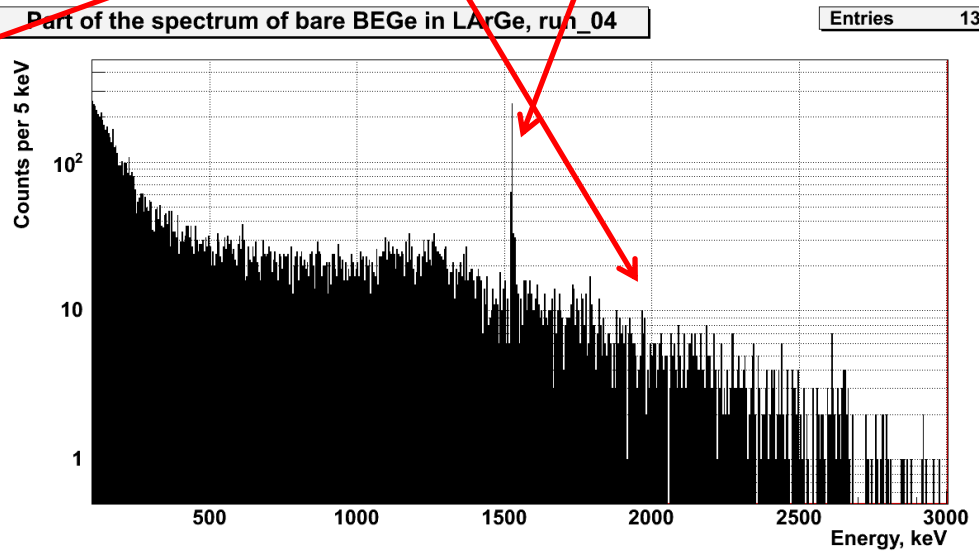
First spectrum taken in the commissioning run of GERDA Phase II. **Background from ^{228}Th at $Q_{\beta\beta}$ suppressed by a factor ~ 400 after applying all cuts.** We expect further improvement of the suppression factor.

^{42}Ar background mitigation



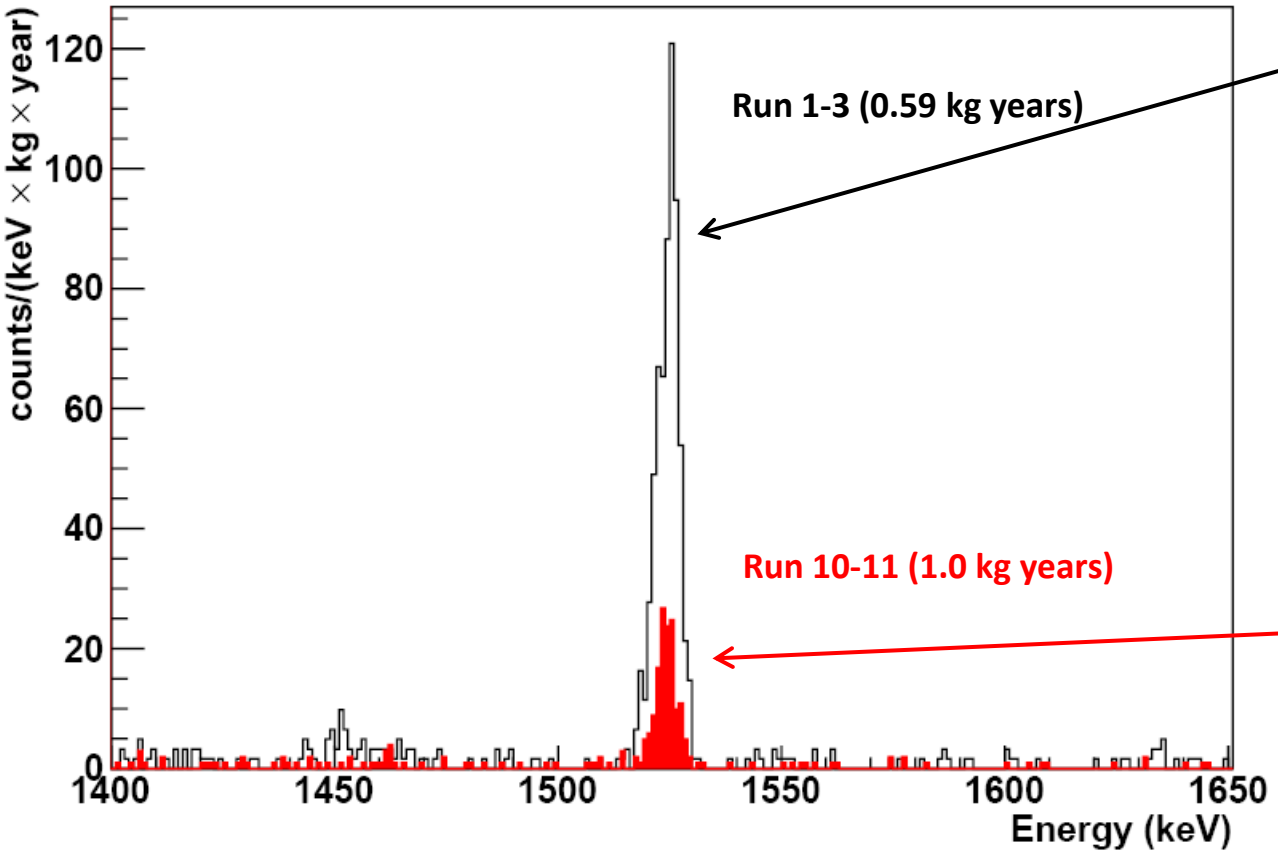


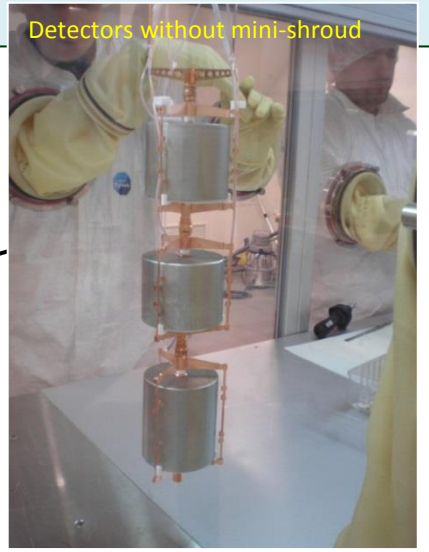




^{42}Ar background mitigation

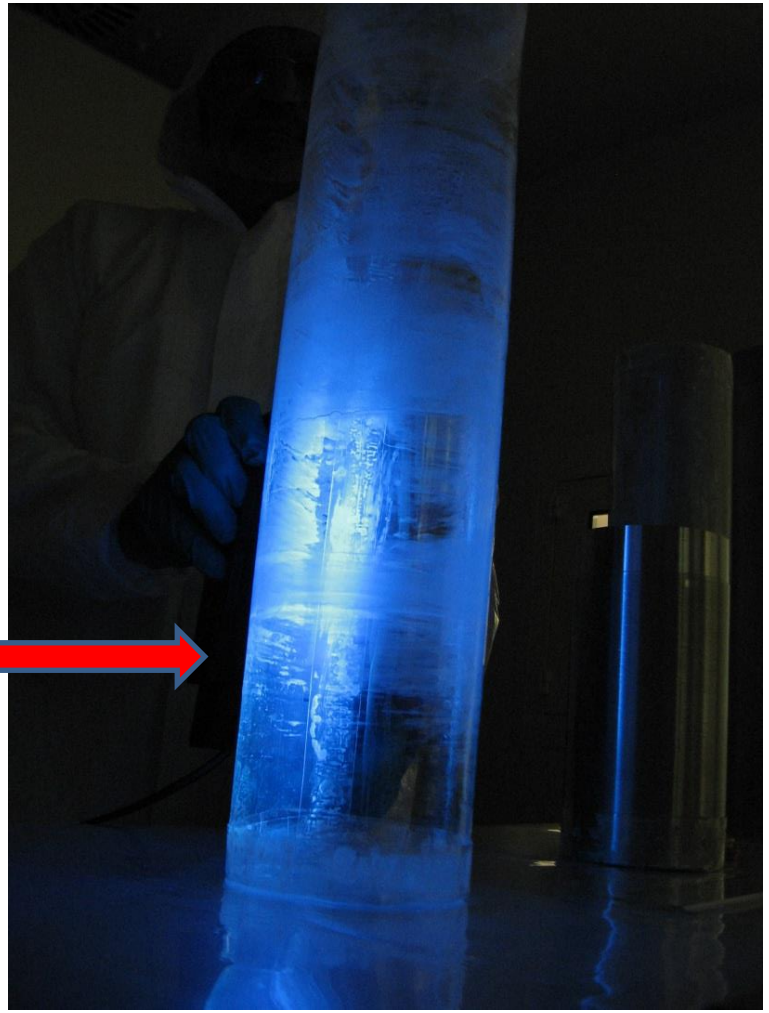
After investigation of ^{42}K background we observed that there is a collection of ^{42}K towards to the detectors. But we found that it can be suppressed with help of so-called copper mini-shroud.



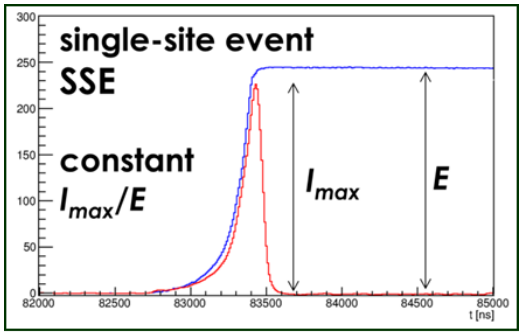


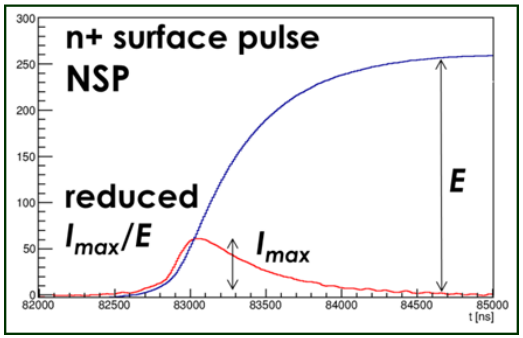
^{42}Ar background mitigation

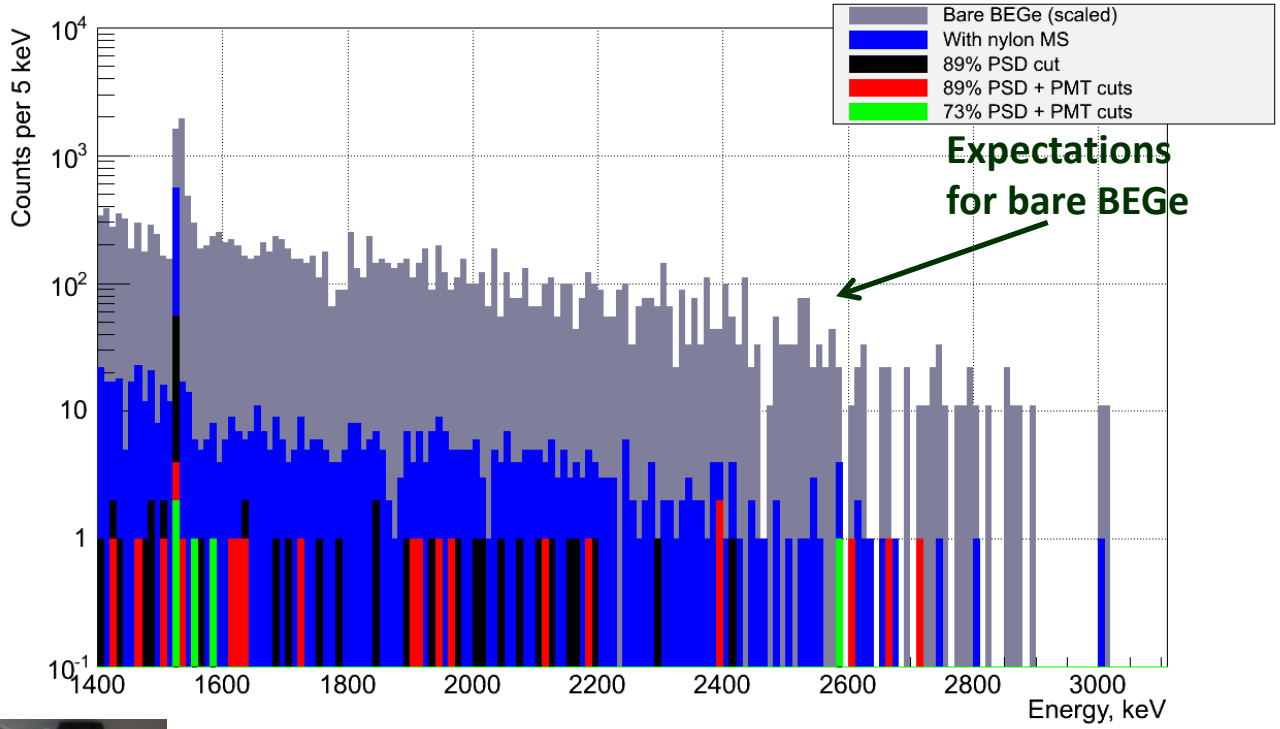
For GERDA Phase II such device would block the scintillation light -> new device has to be developed. Several options were tested. N**ylon mini-shroud (NMS)** covered with wavelength shifter was chosen as mini-shroud.



^{42}Ar background mitigation







In measurements in LArGe test facility accumulated statistics was equivalent approximately to ~ 17 kg·yr in natural argon.
It was shown that with NMS+PSD+PMT suppression it is possible to dramatically decrease ^{42}K background: suppression more than factor of 1000 was demonstrated.

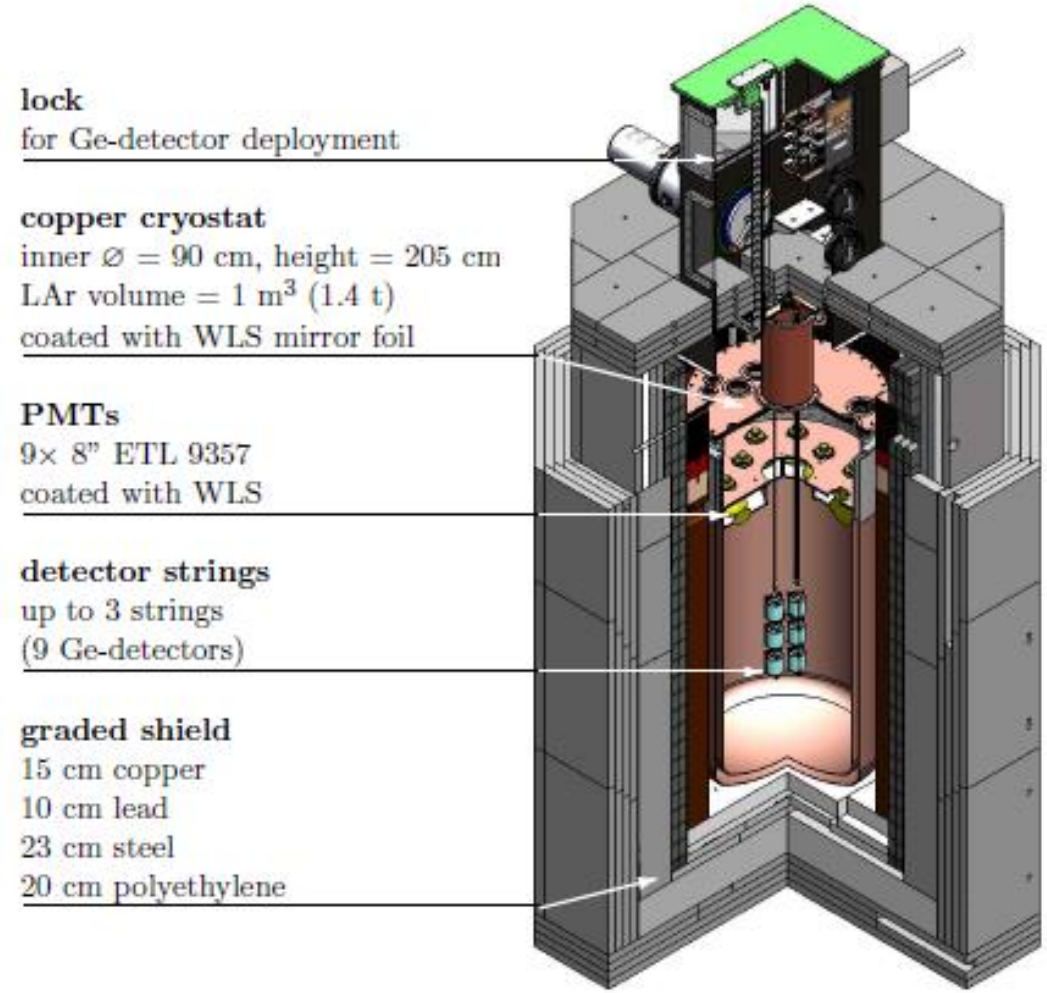
Conclusion

- GERDA Phase I data taking was successfully performed.
- Obtained limit on the half-life of the $0\nu\beta\beta$ decay is $2.1 \cdot 10^{25}$ yr.
- Signal from the previous claim disfavored by GERDA with 99% probability.
- Installation of the GERDA Phase II is ongoing.
- First results of background suppression by LAr scintillation veto are promising.
- More data are coming soon….

Back up slides

LArGe test facility

LArGe low background test facility has been created in order to study the possibility to suppress background by using anticoincidence with liquid Ar scintillation signal detected by PMTs. It was shown that liquid scintillation veto can efficiently suppress the background.



^{42}K background expectations

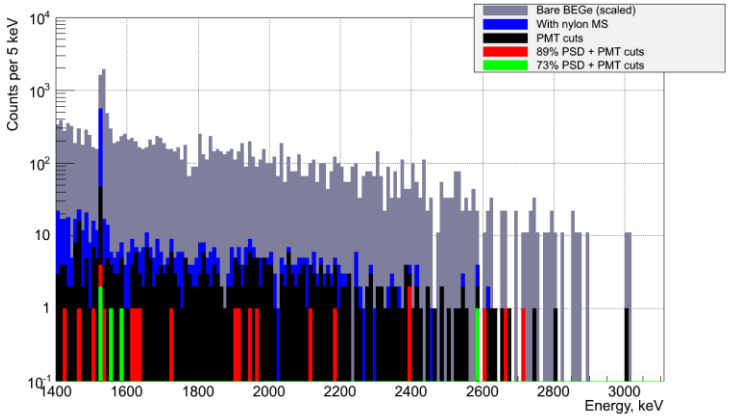


Table 10: Number of counts from ^{42}K and acceptances in the different energy regions before and after applying the cuts with PMT and PSD veto

Experimental conditions	Number of observed events	Suppression factor estimations[1]	Average expectation BI from ^{42}K in 400 keV ROI 10^{-3} cts/(kg·keV·yr)
bare BEGe[2]	4384	1	210-800[3]
NMS	220	15.3	14-52
NMS + 89% PSD + PMT	3	1122	0.19-0.71
NMS + 73% PSD + PMT	0	>1530[4]	<0.14-0.52
no NMS, 89% PSD + PMT[2]	11.2	330	0.9-2.4

[1]Suppression factors are corrected by the observed long-term changes. [2] Scaled by time of the measurements and activity of ^{42}Ar. [3]Based on the different estimations of the measurements in LArGe and GERDA and with the different dead layer thicknesses [13]. [4] 90% C.L.