From GERDA to LEGEND: a view inside two high sensitivity probes on the neutrino nature and mass

GERDA

LEGEND

Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay

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Search for 0νββ decay

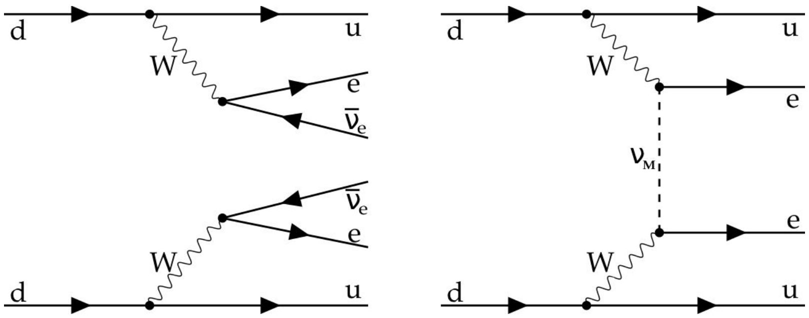
LEGEND
Large Enriched Germanium Experiment for Neutrinoless ββ Decay

GERDA

Study the unknown neutrino properties

Observation of 0νββ decay will imply:

1. neutrino has Majorana nature
2. lepton number violation (ΔL = 2)
3. determination of ν absolute mass (nuclear model dependent)



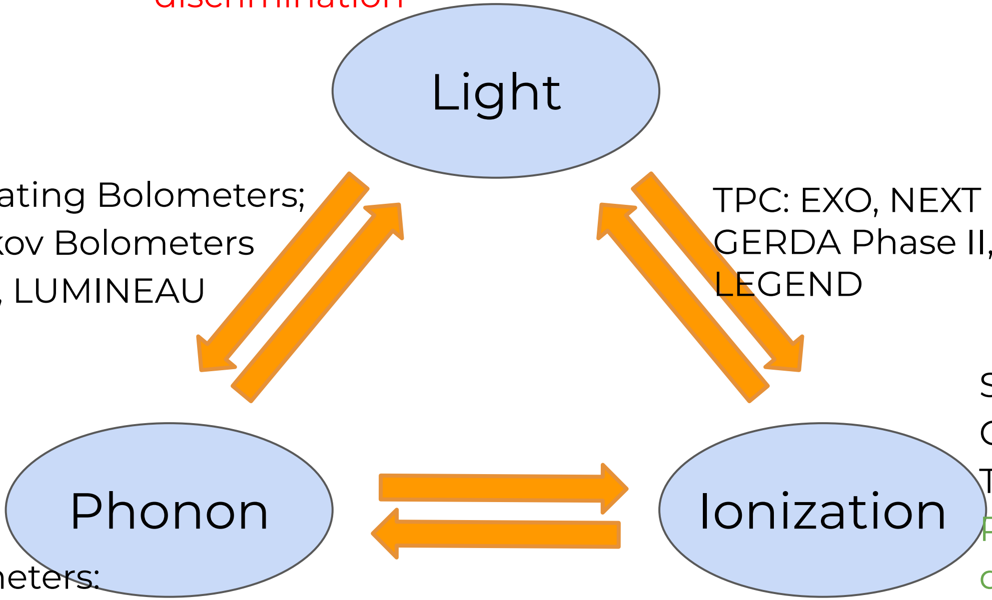
The half life of 0νββ in case of light Majorana neutrino exchange:

$$\left(T^{0\nu}_{1/2}\right)^{-1} = G_{0\nu} \times \left|M_{0\nu}\right|^2 \times \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

- **Phase Space Integral:** well known quantity
- **Nuclear Matrix Element:** most critical ingredient, produces uncertainty in the determination of $m_{\beta\beta}$ (quenching problem)
- **Neutrino Effective Mass:** estimated by measuring $T^{2\nu}_{1/2}$

0νββ: choosing the technique

Liquid Scintillators: Kamland-Zen, SNO+
Scintillating Crystals: Candles
PRO: High Masses possible
CONS: Limited En. Res. Limited Bkg discrimination



Scintillating Bolometers;
Cerenkov Bolometers
CUPID, LUMINEAU

TPC: EXO, NEXT
GERDA Phase II,
LEGEND

Bolometers:
CUORE

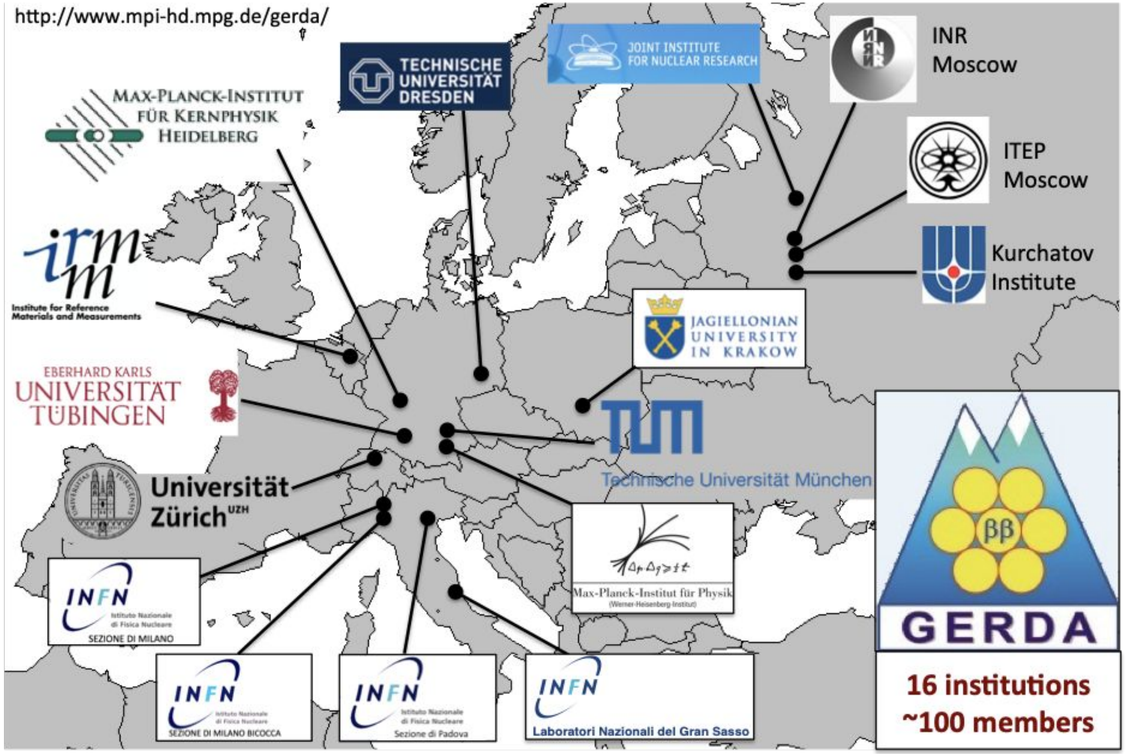
Semiconductor Calorimeters:
GERDA; MAJORANA, LEGEND
Tracking Calorimeters: SuperNEMO; DCBA
PRO: Good En. Res. Good Bkg discrimination
CONS: Difficult/Costly to scale up Masses

Energy of 0νββ for different isotopes

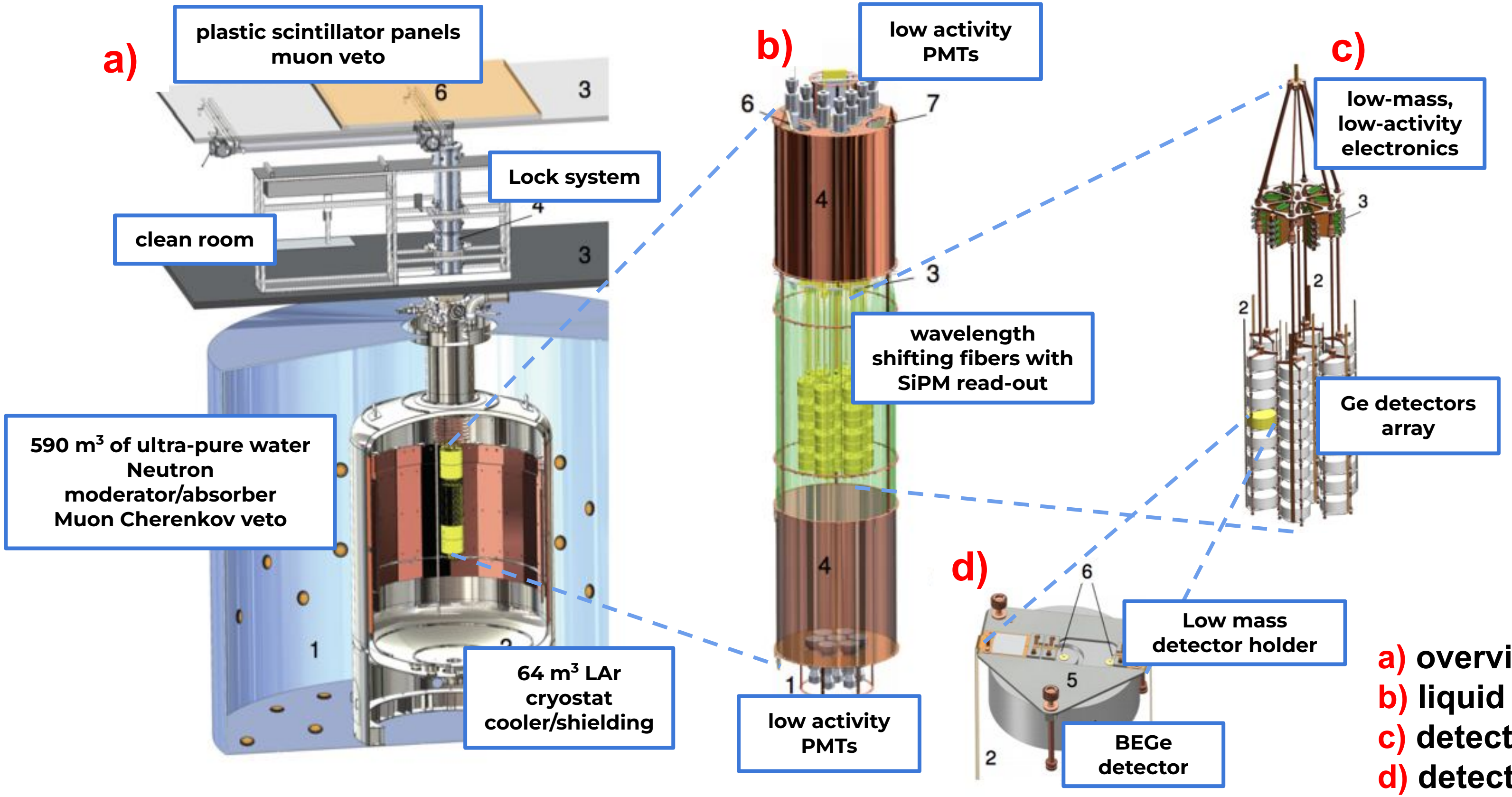
Isotope	**Nat ab.**	$\mathbf{Q_{\beta\beta}}$
^{48}Ca	0.19 %	4262.96(84) keV
^{76}Ge	7.6%	2039.04(16) keV
^{82}Se	8.7%	2997.9(3) keV
^{96}Zr	2.8%	3356.097(86) keV
^{100}Mo	9.6%	3034.40(17) keV
^{116}Cd	7.5%	2813.50(13) keV
^{130}Te	34.5%	2526.97(23) keV
^{136}Xe	8.9%	2457.83(37) keV
^{150}Nd	5.6%	3371.38(20) keV

GERDA Experiment

- In 2004 Heidelberg-Moscow experiment sub-group claims the observation of 0νββ observation ($T^{0\nu}_{1/2}$=1.19 10^{25} y) [Phys. Lett. B 586, 3–4, 2004]
- In 2006 GERDA Collaborations borns with the aim to confirm/disprove the claim
- 16 institutions from Italy, Germany, Russia, Switzerland, Poland
- GERDA starts data taking 2010 and stopped in 2020



GERDA Setup



a) overview
b) liquid argon veto (LAr)
c) detector array
d) detector module

GERDA final setup

Semi-Coaxial detectors: 15.6 kg

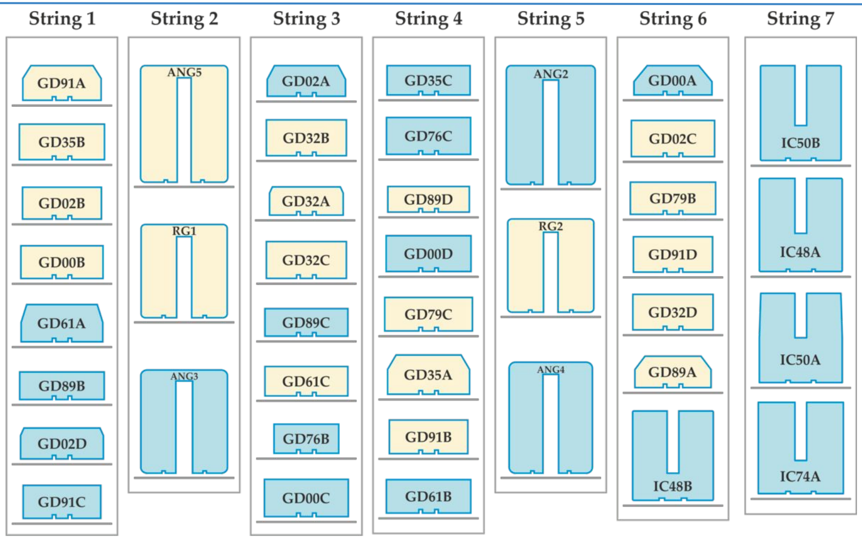
- from previous experiments (HdM, IGEX)
- energy resolution: 3.6 keV (FWHM) Qββ

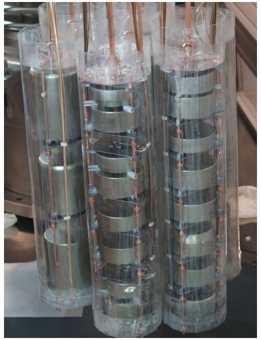
BEGe detectors: 20 kg

- produced for Phase II
- energy resolution: 3.0 keV (FWHM) Qββ
- improved Pulse Shape Discrimination with A/E (current-amplitude/energy)

Inverted-Coaxial detectors: 9.5 kg

- In production for LEGEND-200
- Excellent resolution and pulse shape discrimination performance [A. Domula et al., NIM A891, 106 (2018)]
- Lower surface to volume ratio

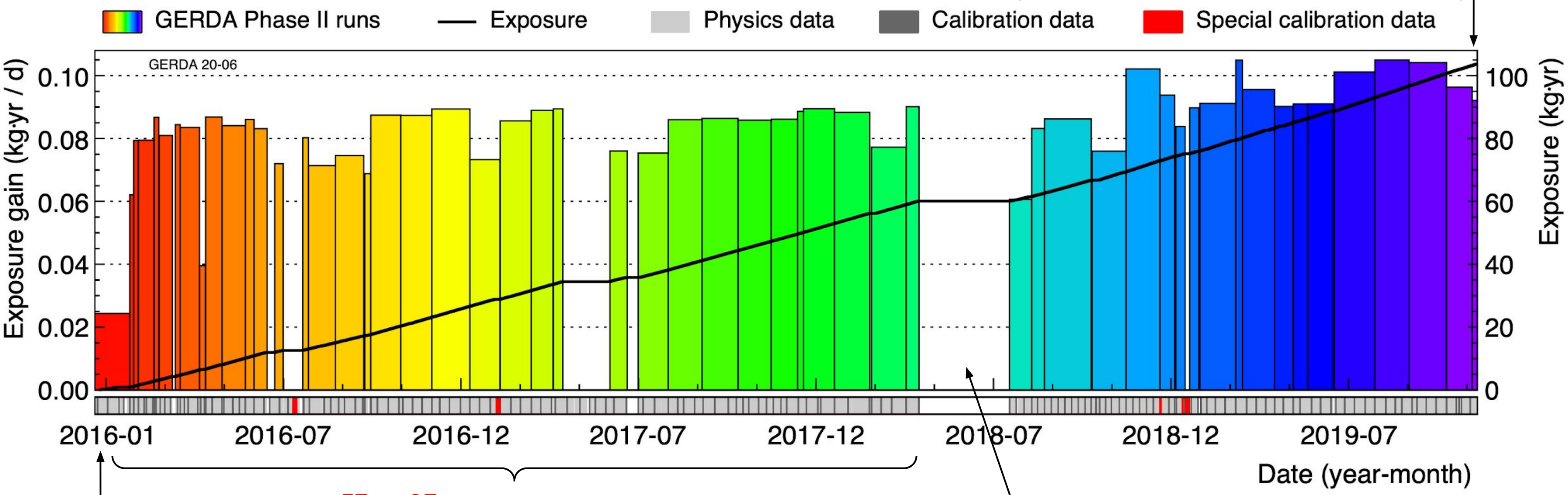




Final Phase II exposure

run 95 to 114
post-upgrade: **481 d**
with **0.091 kg yr/d**

~ 4 years
last event on
11 Nov 2019



~ 4 years
First event on
20 Dec 2015

run 53 to 93
pre-upgrade: **848 d** with **0.071 kg yr/d**

upgrade: **93 d**

Energy Distribution and results

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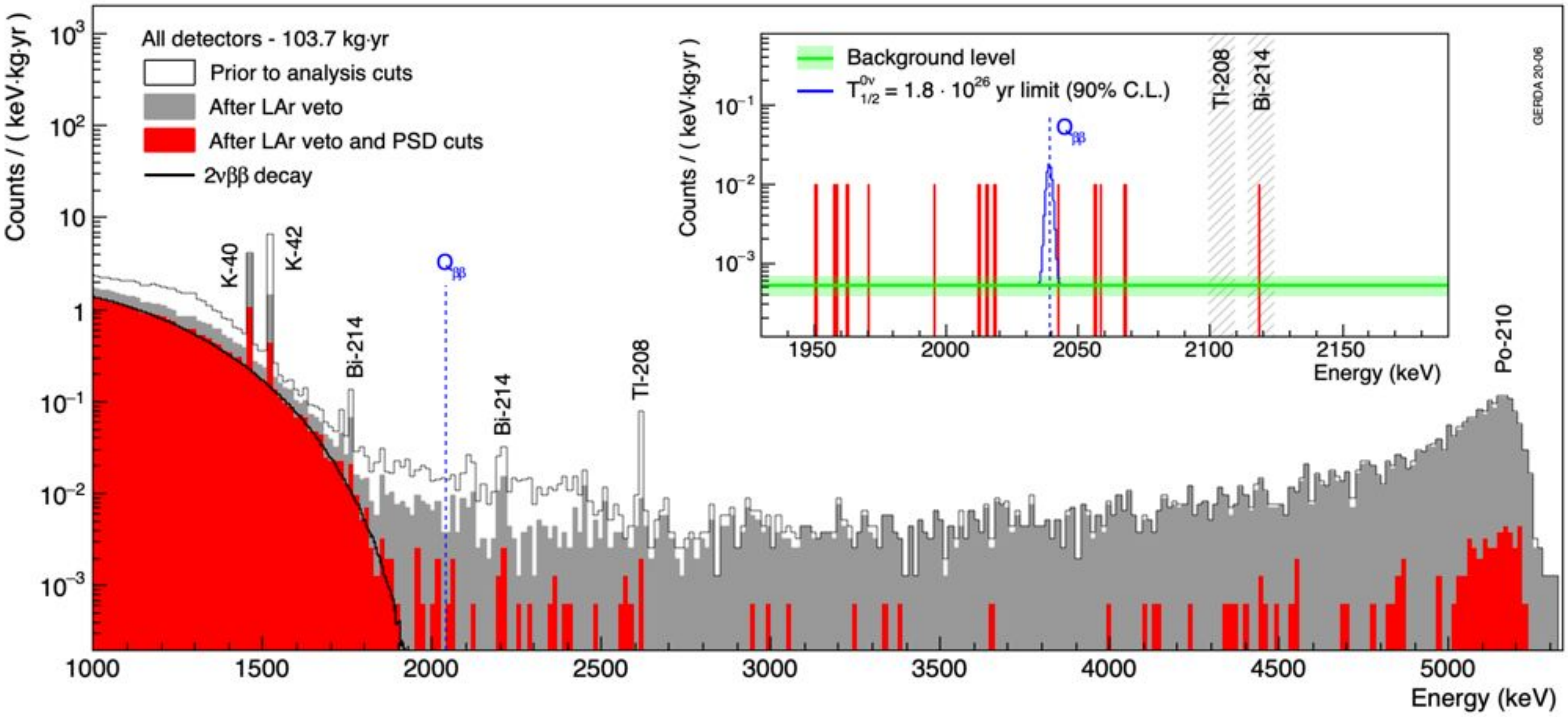
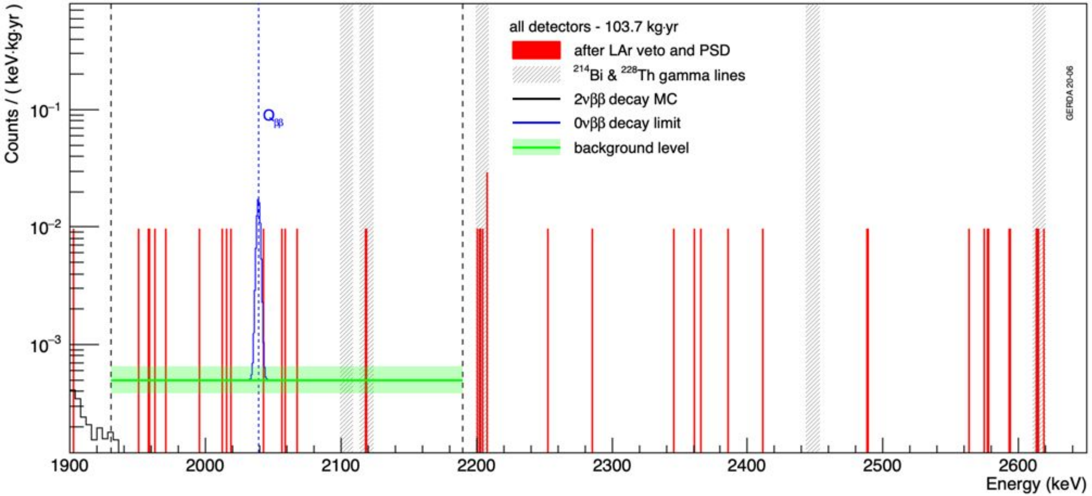


Statistical analysis

13 events are found in the whole data taking period in the fit range of 240 keV range around $Q_{\beta\beta}$ (excluding two **γ**-line regions). Only one event (we name it "primo") is within 3σ. **3 events are cut by refined alfa cut**



Excluding know **γ**-lines region → flatness hypothesys of Background verified

Phase II Frequentist analysis:

- Median Sensitivity

$T^{0v}_{1/2} > 1.8 \times 10^{26}$ yr (90% CL)

- Best fit → No signal

$T^{0v}_{1/2} > 1.5 \times 10^{26}$ yr (90% CL)
$B = 5.2^{+1.6}_{-1.3} \times 10^{-4}$ ckky (68% CL)

- Phase II+ Phase I (127.2 kgyr)

$T^{0v}_{1/2} > 1.8 \times 10^{26}$ yr (90% CL)

Phase II Bayesian analysis:

- Best fit → No signal
- Flat prior ($0 \div 10^{-24}$ 1/yr)
  $T^{0v}_{1/2} > 1.4 \times 10^{26}$ yr (90% CL)
- Prior $\propto 1/S^{½}$ ($0 \div 10^{-24}$ 1/yr)
  $T^{0v}_{1/2} > 2.3 \times 10^{26}$ yr (90% CL)

As prior gives higher probabilities to low values of S

Comparison of Experimental Results

		Tot. M Isot. [kg]	Design Achi.vd BI [cts/kevkgy]	Design Achi.vd FWHM [keV]	Exposure [kg·y]	$T_{1/2}$ Sensitivity (90%CL) [y]	$T_{1/2}$ Achieved Limit (90%CL) [y]	m_{ee} Limit (90%CL) [meV]
Gerda II - Gerda II	^{76}Ge	31.0 31.0	10^{-3} $0.36 \cdot 10^{-3}$	< 4 3.0-3.7	~100 103.7	> 10^{26}	$1.8 \cdot 10^{26}$	90-150 80-182
Majorana Demonstrator	^{76}Ge	27.1	<10^{-3} $4.7 \cdot 10^{-3}$	< 4 2.5	26	>10^{26} $4.8 \cdot 10^{25}$	$2.7 \cdot 10^{25}$	200-433
n-EXO EXO 200 ult. EXO 200	^{136}Xe	5000 200	$1.7 \cdot 10^{-3}$	73 112	100	$1.9 \cdot 10^{25}$	$1.1 \cdot 10^{25}$	10 50 170-490
KZ comb. Kam-Zen II Kam-Zen II	^{136}Xe	348 348	$3.0 \cdot 10^{-4}$ $6.0 \cdot 10^{-4}$	265 265 285	138 126 29.6	$5.6 \cdot 10^{25}$	$1.07 \cdot 10^{26}$ $9.6 \cdot 10^{25}$ $1.3 \cdot 10^{25}$	50 -160
Cuore Cuore	^{130}Te	206	10^{-2} $1.38 \cdot 10^{-2}$	5 7.0	1000 372.5	$9.5 \cdot 10^{25}$ $1.7 \cdot 10^{25}$	$3.2 \cdot 10^{25}$	50-190 75-350
CUPID CUPID-0	^{100}Mo ^{76}Se		$3.5 \cdot 10^{-3}$	20	5.29	$5.0 \cdot 10^{24}$	$3.5 \cdot 10^{24}$	311-638

If 2004 claim of $0\nu\beta\beta$ evidence ($1.19\ 10^{25}$ y) were true GERDA would observe ~30 events

RED: **projected sensitivity**