Search for neutrinoless double beta decay with the GERDA experiment

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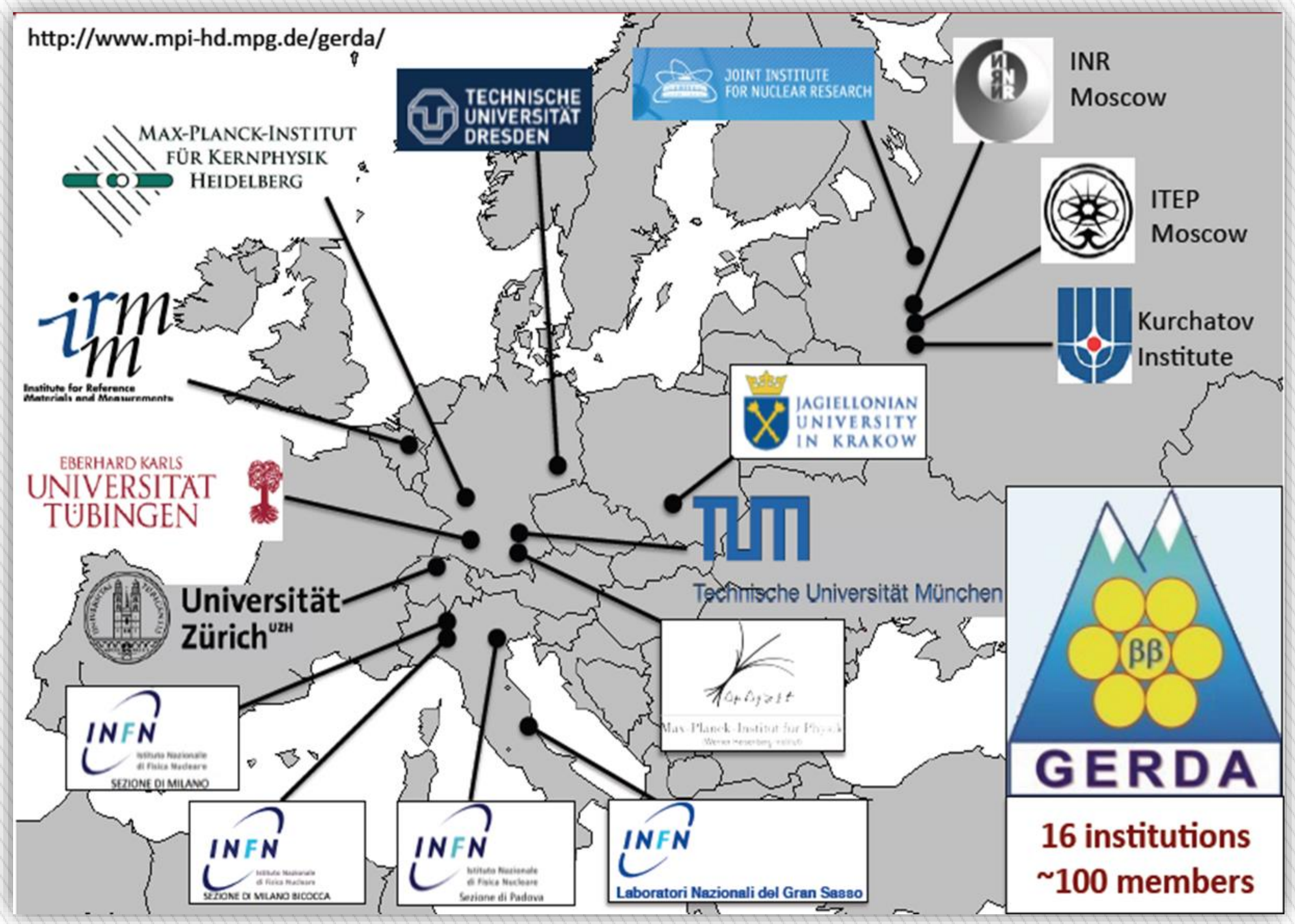
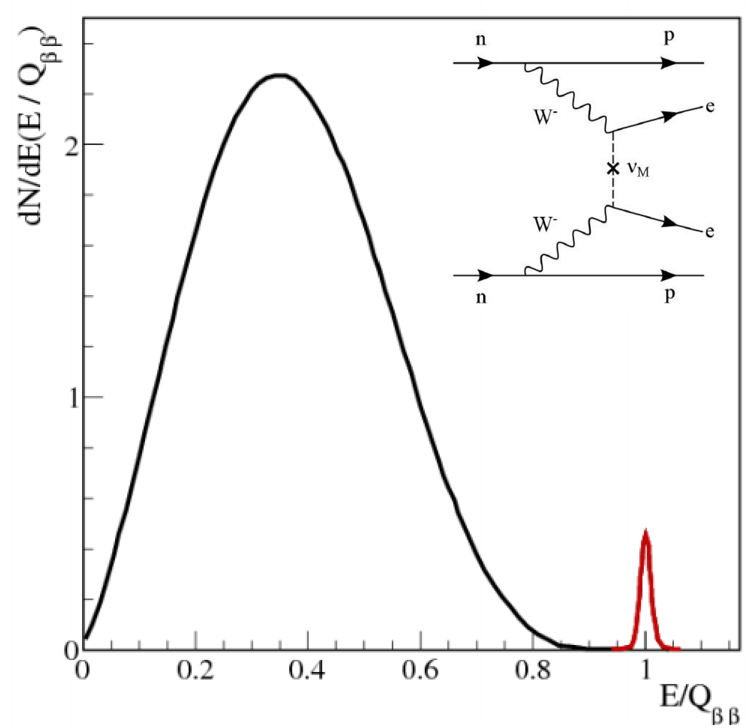
LES RENCONTRES DE PHYSIQUE DE
LA VALLEE D'AOSTE
Results and Perspectives in Particle Physics
La Thuile, Aosta Valley (Italy)
March 5-11, 2017

» The collaboration



» 0νββ and 2νββ decay



coupling strength ~ $m_{\beta\beta} = \sum_{i=1}^{3} U_{ei}^2\, m_i$

function of

- neutrino mixing parameters
- lightest neutrino mass
- 2 Majorana phases

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

effective neutrino mass → $m_{\beta\beta}$

phase space integral → $G_{0\nu}$

nuclear matrix element → $M_{0\nu}$

» GERDA: Ge in LAr @ Gran Sasso

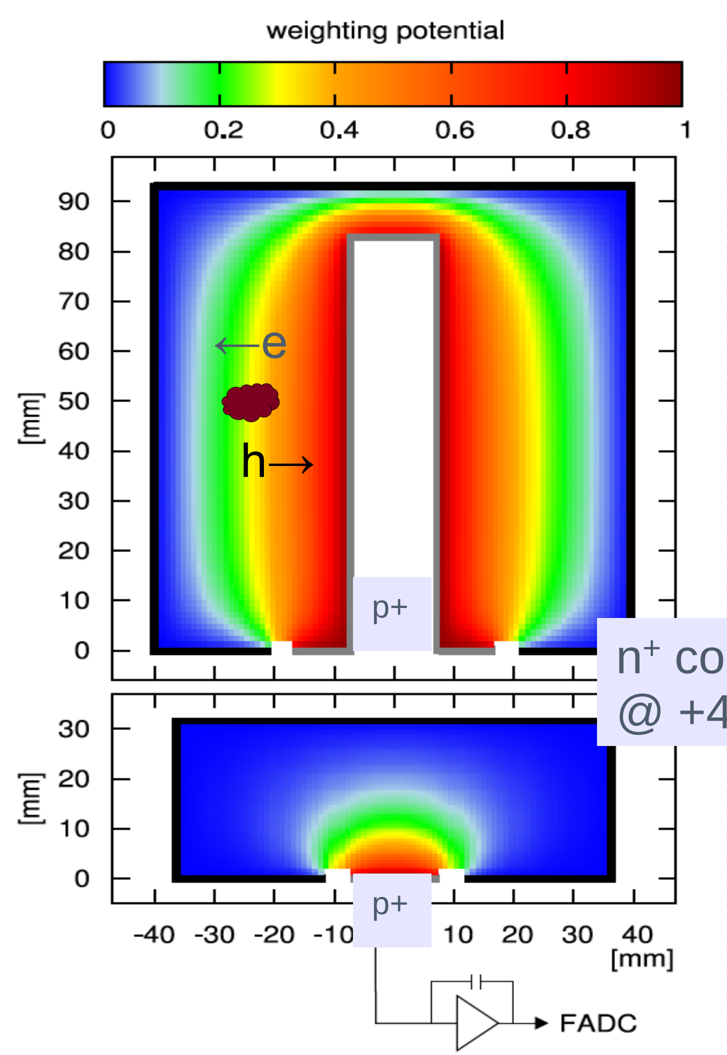
EPJ C73 (2013) 2330 based on idea of G. Heusser (1995)

In the experiment bare germanium detectors are operated in liquid argon (LAr) – active veto.

The detectors are made from germanium with the ^{76}Ge isotope fraction enriched from 7.8% to about 87 %.

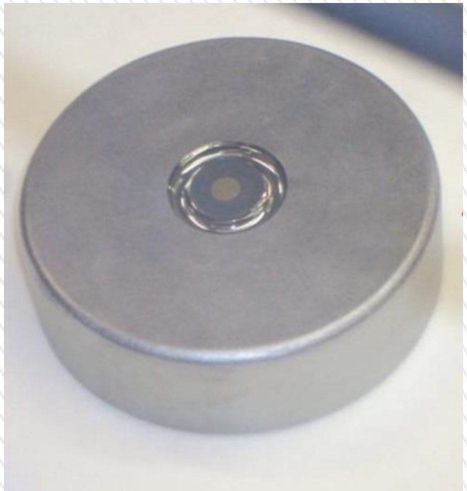
Since source and detector of $0\nu\beta\beta$ decay are identical in this calorimetric approach the detection efficiency is high.

» GERDA Phase II: Final Configuration



n⁺ contact @ +4 kV

semi-coaxial



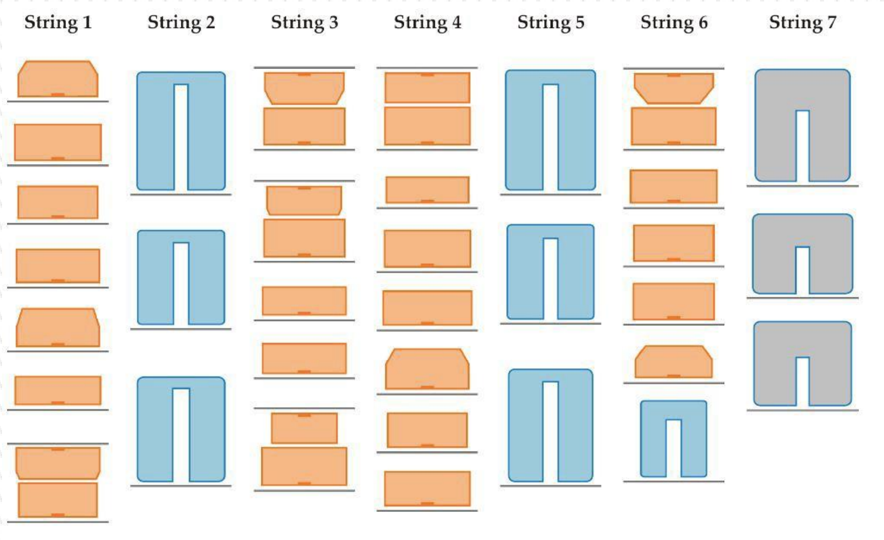
BEGe

» GERDA Phase II: Final Configuration

40 detectors arranged in 7 strings:

- 30 ^{enr}Ge BEGes (20 kg)
- 7 ^{enr}Ge coaxials (15.8 kg)
- 3 natural coaxials (7.6 kg)

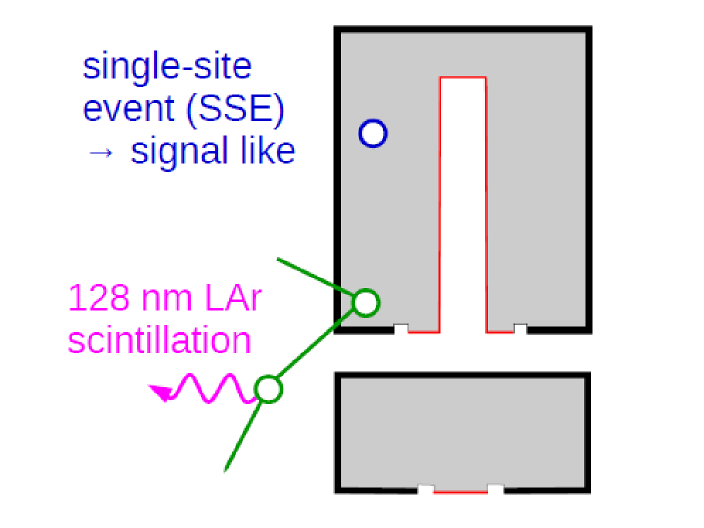
35.8 kg of ^{enr}Ge



First Phase II data release:

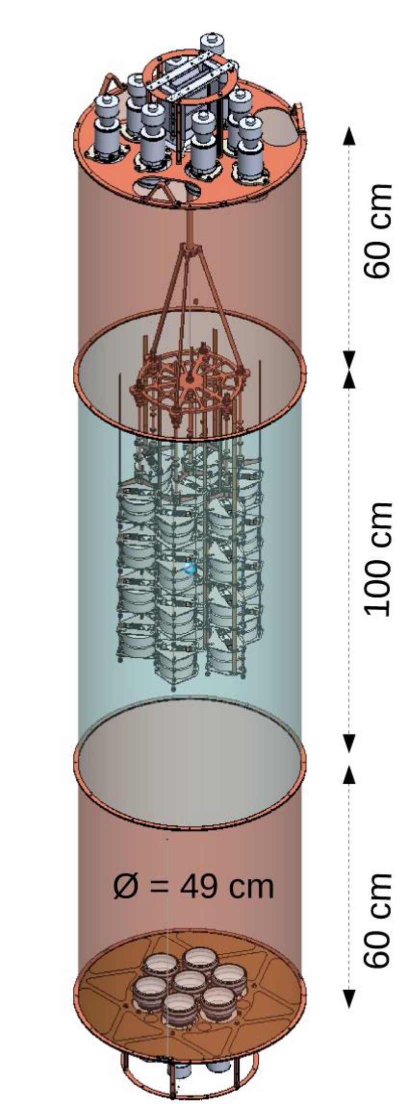
- 25 Dec 2015 – 01 Jun 2016
- 82% average duty cycle
- exposure used for analysis:
  5.8 kg · yr for enriched BEGe
  5.0 kg · yr for enriched coax
- blinding window $Q_{\beta\beta} \pm 25$ keV

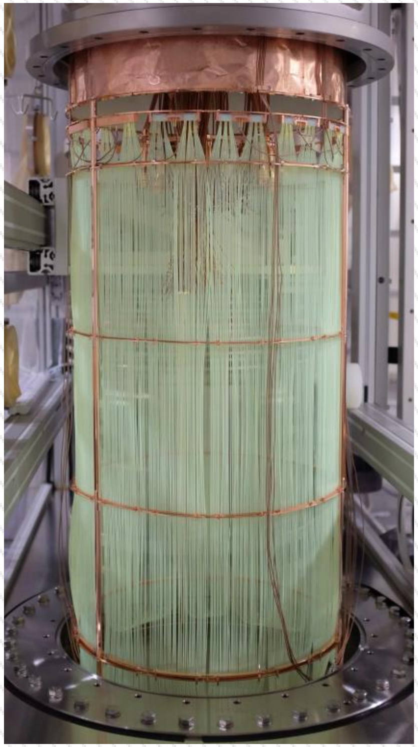
» GERDA Phase II: Liquid Argon Veto



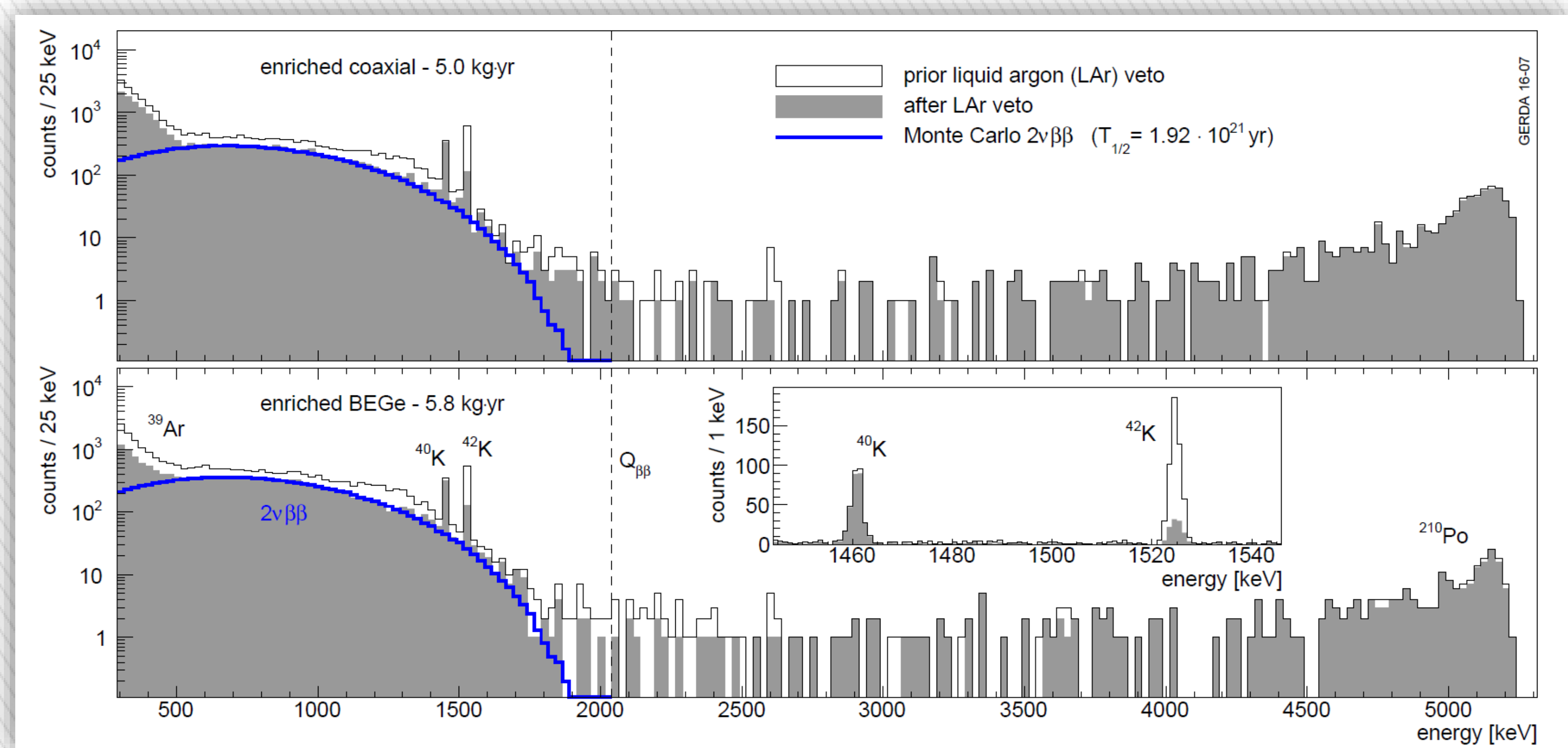
Hybrid design:

- 16 x 3” low background PMTs Ham RG11065-10/20 MOD
- 810 x scintillating fibers coupled to 90 KETEK SiPMs
- 100 µm Cu shrouds with wavelength shift TETRATEX foil





» GERDA Phase II: Liquid Argon Veto



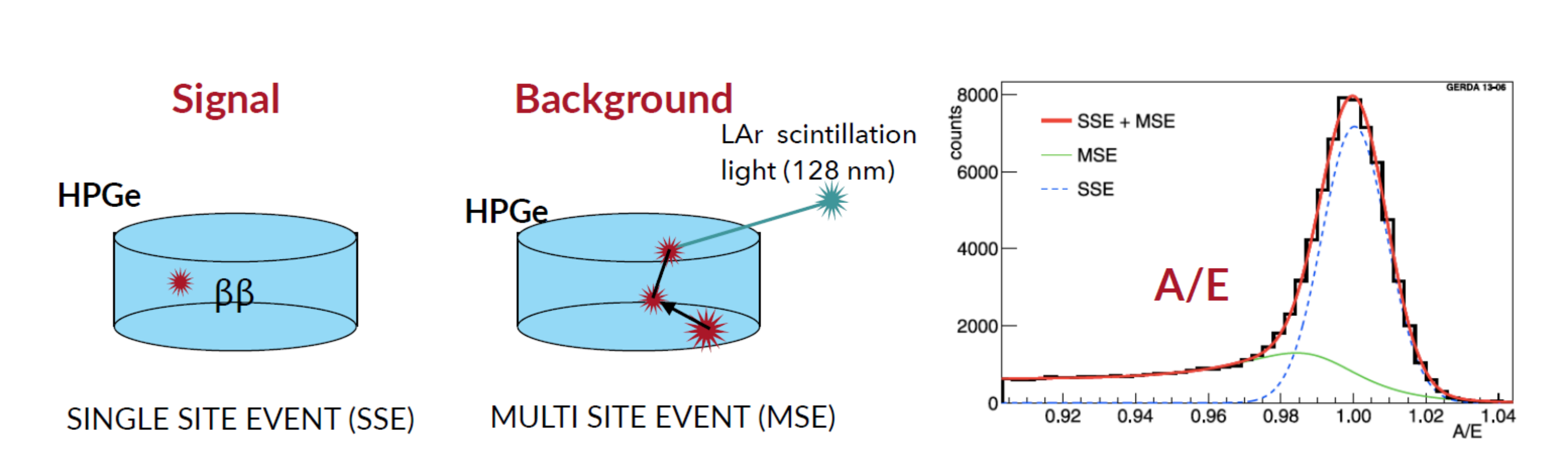
Energy spectra of Phase II data sets before (open histogram) and after argon veto cut (filled histogram). The blue lines are the expected 2νββ spectra for our recent half-life measurement.

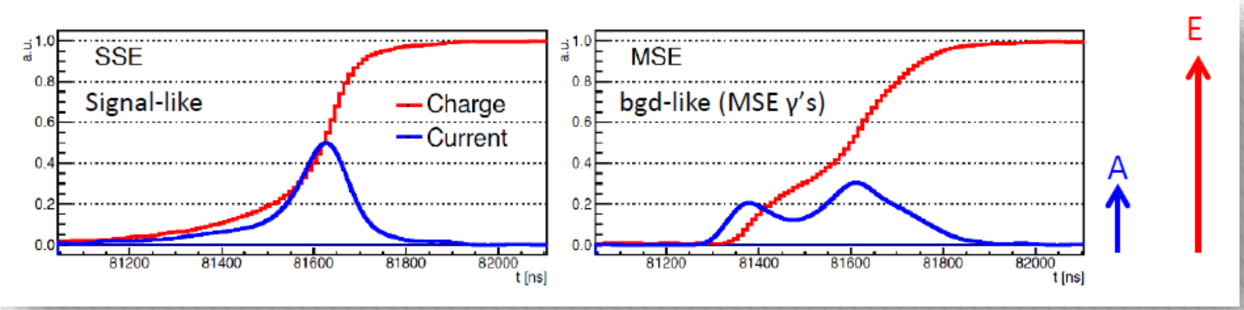
The power of the LAr veto is best demonstrated by the ^{42}K line at 1525 keV which is suppressed by a factor ~5 due to the β particle depositing up to 2 MeV energy in the LAr.

» PSD for BEGe detectors

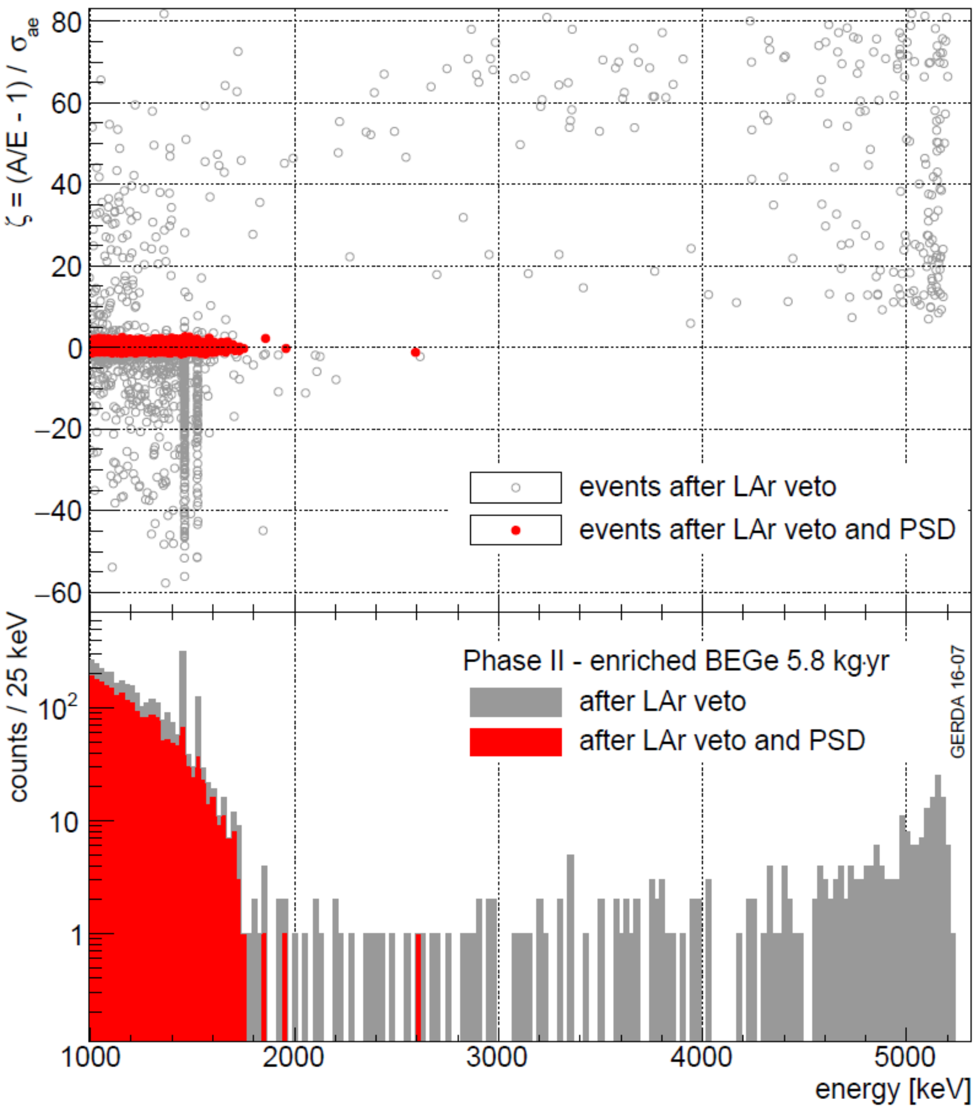
The geometry of BEGe detectors allows to apply a simple mono-parametric PSD based on the maximum of the detector current pulse A normalized to the total Energy.

A/E = amplitude of Current pulse /amplitude of Charge pulse





» PSD for BEGe detectors



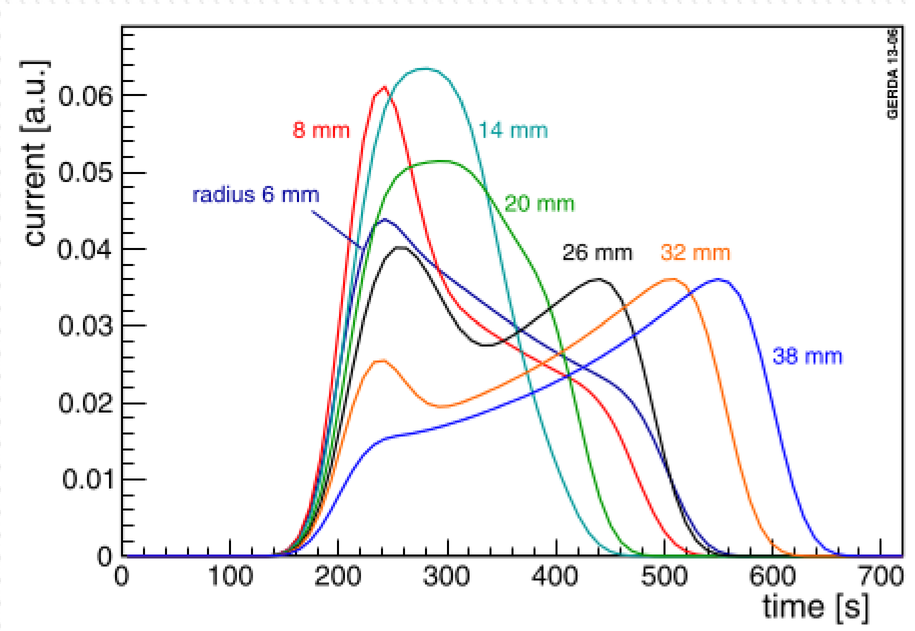
The energy dependence of the mean and the resolution of A/E are measured for every detector with calibration events.

After correcting for these dependences and normalizing the mean A/E of DEP events to 1, the acceptance range is determined for each detector individually: the lower cut is set to keep 90% of DEP events.

Events marked in red survive the PSD selection. Below 1.7 MeV $2\nu\beta\beta$ events dominate with a survival fraction of 85%. The average $0\nu\beta\beta$ survival fraction is (87 ± 2)%

Potassium peaks and Compton scattered photons reconstruct at A/E < 1 (below the SSE band). α events are easily removed.

» PSD for coaxial detectors

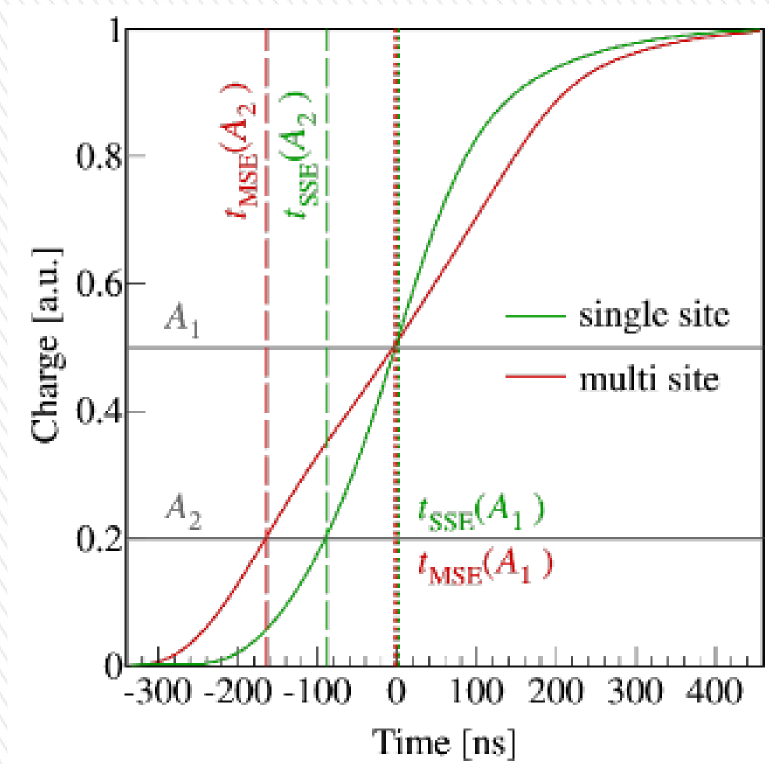


different shapes → no simple parameter → neural network:

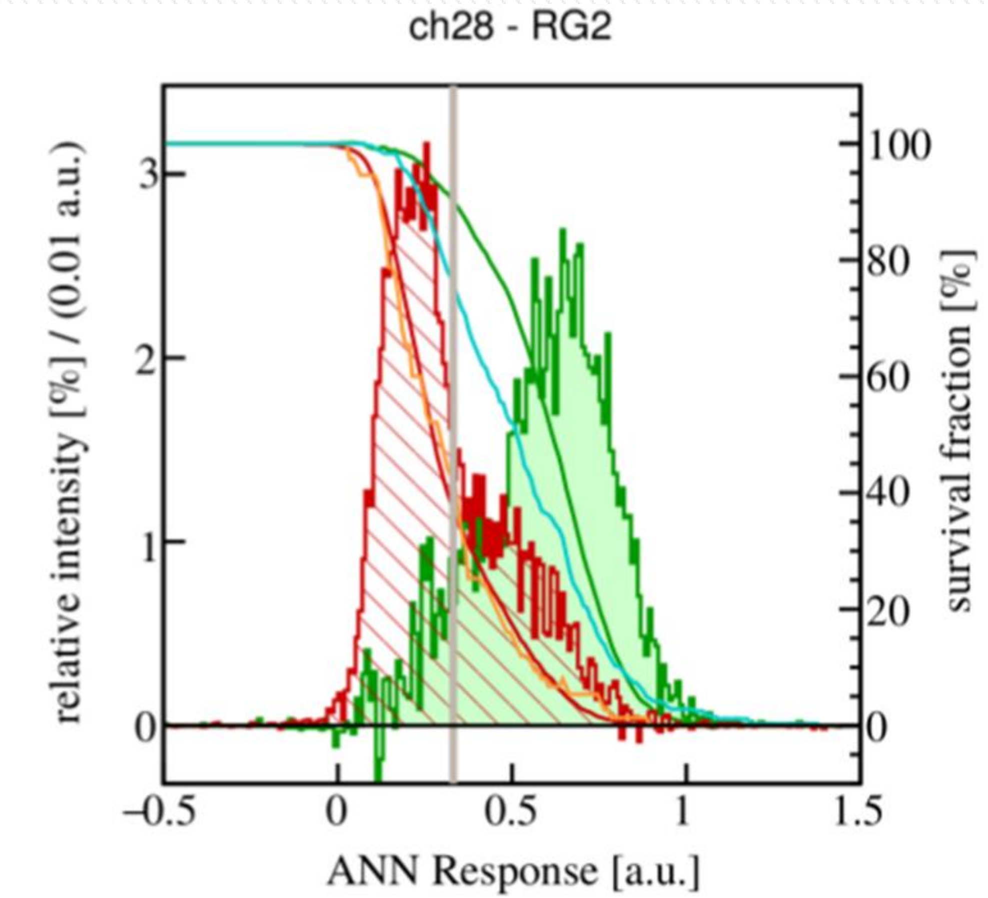
2 methods using different inputs & training samples

50 time stamps when charge reaches 1%, 3%, … 99% of maximum

training with
DEP (1593 keV) = signal
and 1621 keV line from ^{212}Bi = bkg
(all calibrations combined)
cut at 90% survival of DEP peak



» PSD for coaxial detectors



The PSD for SSE/MSE is identical to the one used in Phase I.

We introduced second neural network to discriminate SSE from α surface events.

The cut on the neural network qualifier is set to yield a survival fraction of DEP events of 90% for each detector.

For the determination of the $0\nu\beta\beta$ efficiency, $2\nu\beta\beta$ events in physics data and a complete Monte Carlo simulation of physics data and calibration data are used.

We find a survival fraction for $0\nu\beta\beta$ events of (85 ± 5)%

» GERDA Phase II: Unblinding of first data set

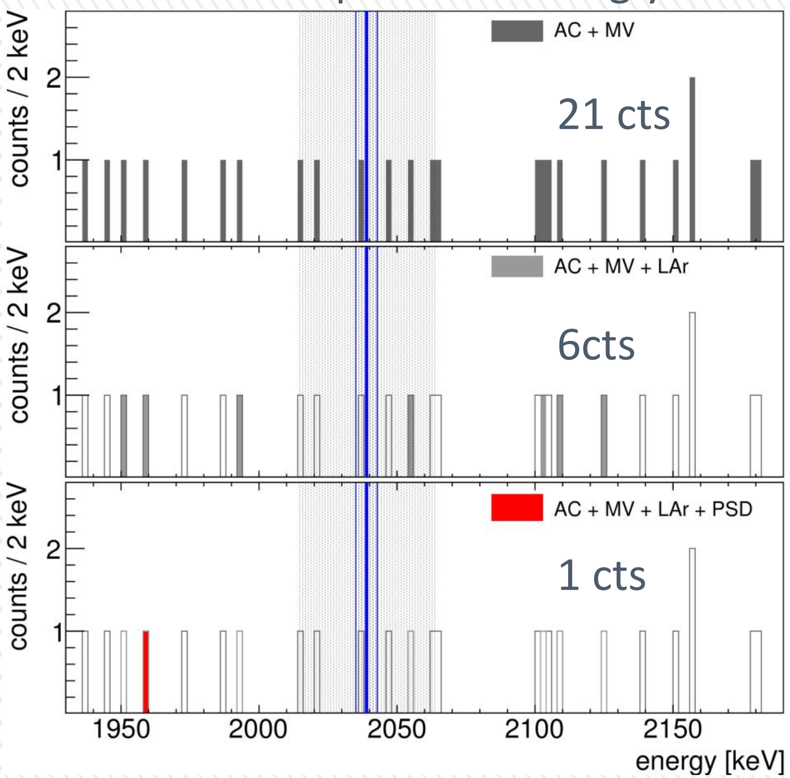
GERDA Collaboration Meeting on Ringberg castle (GER)
June 15-18, 2016

Final steps prior unblinding the $Q_{\beta\beta}$ ±25 keV window:

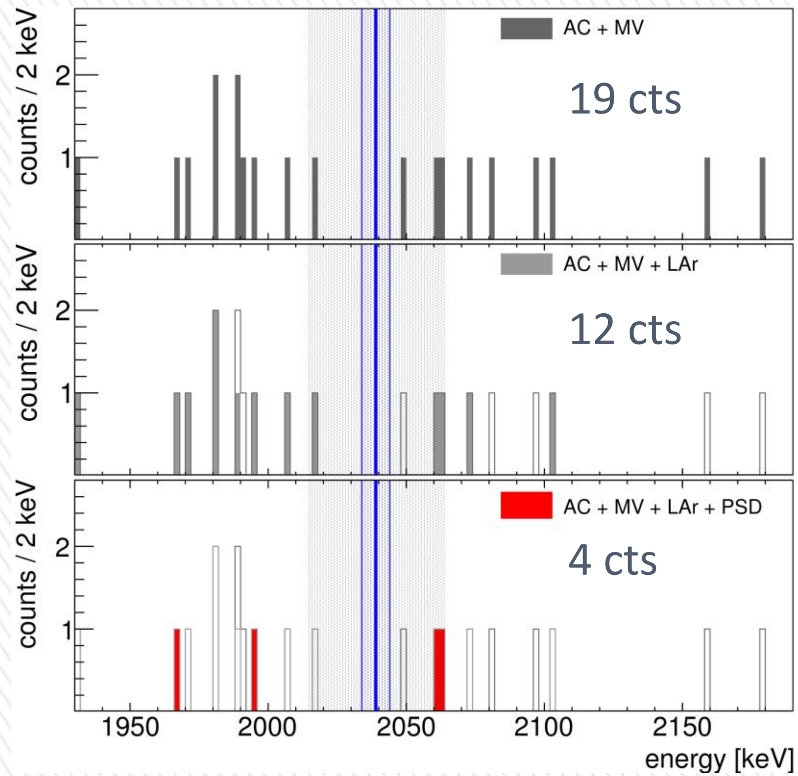
- Freeze analysis cuts (energy reconstruction, quality cuts, flags...)
- Freeze data periods from Phase 1 and 2
- Freeze background model
- Freeze LAr veto and PSD cuts for BEGe and Coax

» GERDA Phase II: Unblinding of first data set

BEGe: Exposure = 5.8 kg·yr



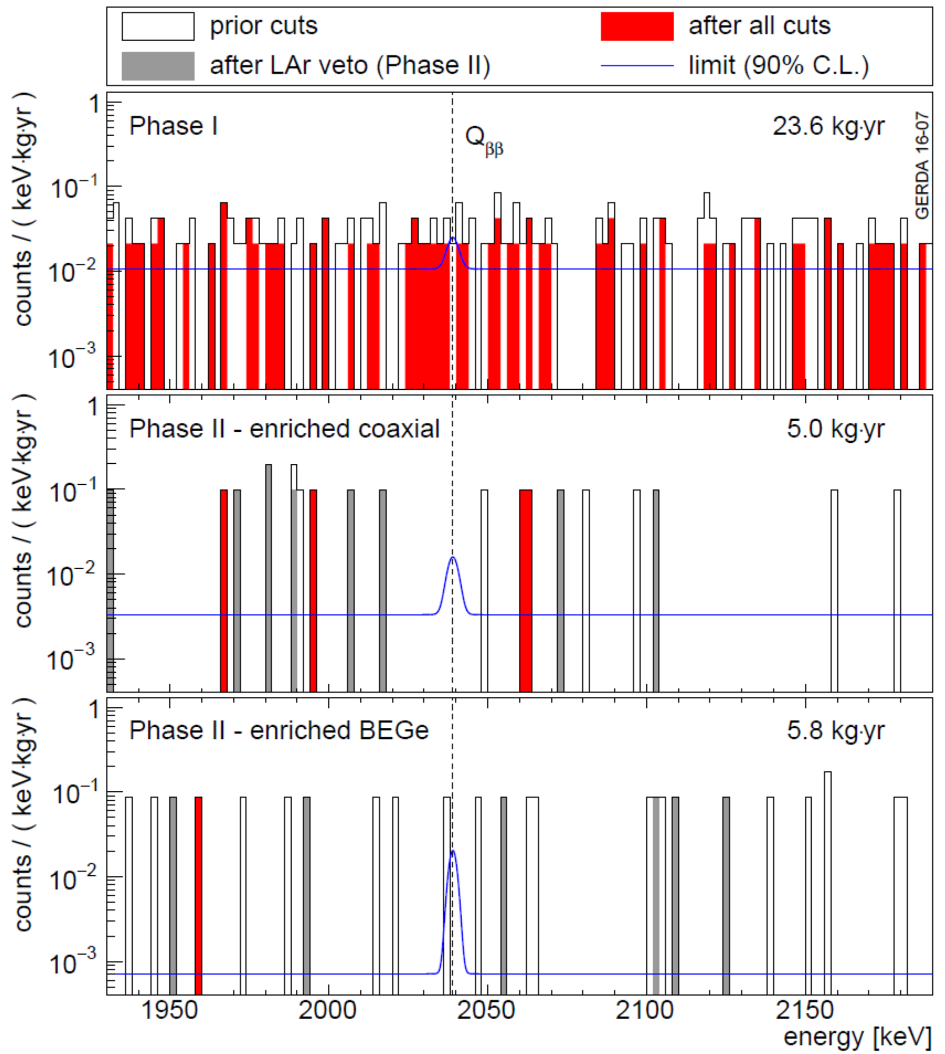
Coax: Exposure = 5.0 kg·yr



AC	Anti-Coincidence between detectors
MV	Muon Veto
LAr	Liquid Argon veto
PSD	Pulse Shape Discrimination

→ Like in Phase I,
no hint for γ-line at $Q_{\beta\beta}$
Background is flat

» GERDA Phase II: $T^{0\nu}_{1/2}$ results



Combined Phase I data (top), Phase II coaxial (middle) and BEGe detector spectra (bottom) in the analysis window.

The red histogram is the final spectrum, the filled grey one without pulse shape discrimination and the open one in addition without argon veto cut.

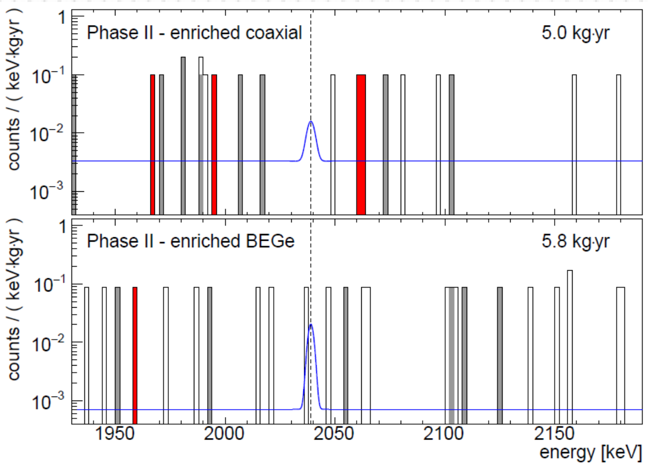
The blue line is the fitted spectrum together with a hypothetical signal corresponding to the 90 % C.L. limit of

$$T^{0\nu}_{1/2} > 5.3 \cdot 10^{25}\ \text{yr}$$

accepted by nature

» Background Analysis (from 1930 to 2190 keV)

data set	exposure [kg·yr]	FWHM [keV]	efficiency	BI 10^{-3}cts/(keV · kg · yr)
PI golden	17.9	4.3(1)	0.57(3)	11 ± 2
PI silver	1.3	4.3(1)	0.57(3)	30 ± 10
PI BEGe	2.4	2.7(2)	0.66(2)	5^{+4}_{-3}
PI extra	1.9	4.2(2)	0.58(4)	5^{+4}_{-3}
PIIa coaxial	5.0	4.0(2)	0.53(5)	$3.5^{+2.1}_{-1.5}$
PIIa BEGe	5.8	3.0(2)	0.60(2)	$0.7^{+1.1}_{-0.5}$



List of data sets, exposures (for total mass), energy resolutions in FWHM, efficiencies (including enrichment, active mass, reconstruction efficiencies and dead times) and background indices (BI) in the analysis window.

The GERDA Phase II background goal is reached – first background free experiment.

» Summary & future plans

- **GERDA Phase II is running stable since December 2015**

- **Result from Phase I + first Phase II period:**

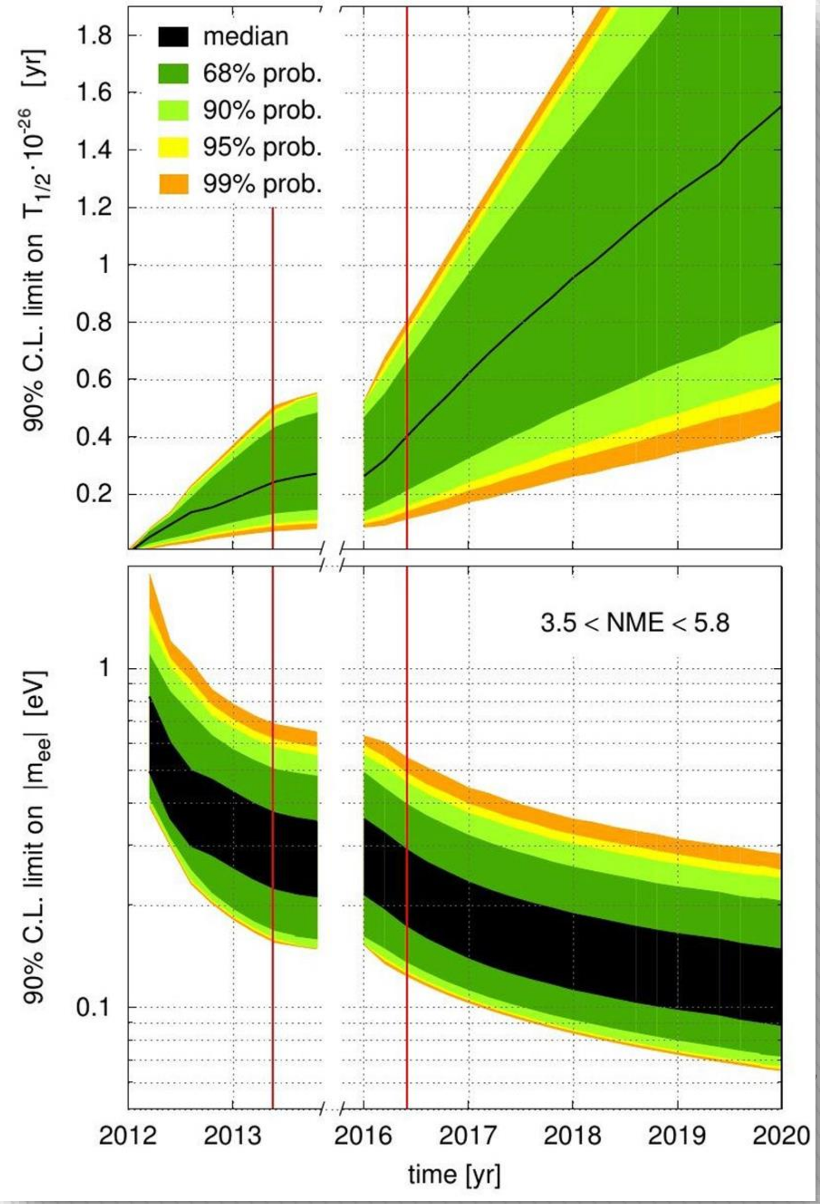
  - **Sensitivity: $T^{0\nu}_{1/2} > 4.0 \cdot 10^{25}$ yr (90% CL)**
  - **we found no signal**

    $T^{0\nu}_{1/2} > 5.3 \cdot 10^{25}$ yr (90% CL)
    $m_{\beta\beta} < 0.15 – 0.33$ eV

    arXiv:1703.00570

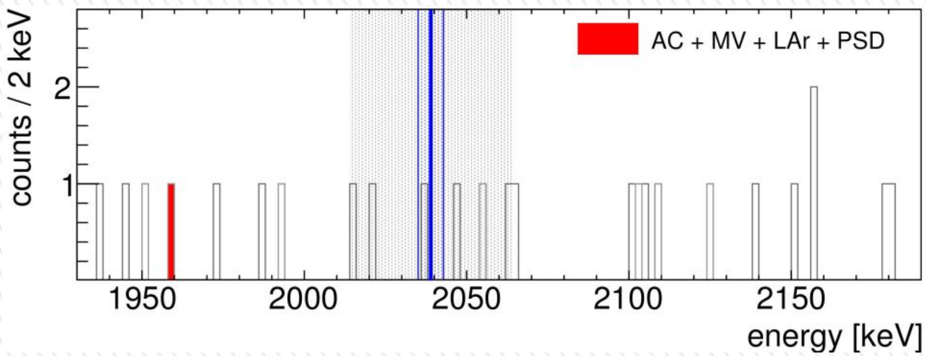
  - the lowest background ever achieved:
  BEGe: $0.7\ ^{+1.1}_{-0.5} \cdot 10^{-3}$ [cts/(keV · kg · yr)]

- **Goal for Phase II (next 3-4 yr):**
  - reach 100 kg · yr of exposure
  - improve the limits on $T^{0\nu}_{1/2}$ ~10^{26} yr
  - $m_{\beta\beta}$ ~ 0.1 eV



» Summary & future plans

- **GERDA is the first background-free experiment - background in FWHM around order of magnitude lower than for other experiments**



- **The concept of using bare germanium detectors in LAr has the best discovery potential (resolution, PSD performance + LAr active shielding)**

- **Makes sense to continue: LEGEND collaboration formed for ultimate goal of 1000 kg Ge. Our first phase will be 200 kg as the GERDA cryostat can hold it.**

  The discovery sensitivity would then improve by an order of magnitude to a half-life of 10^{27} yr.

  More ambitious 1 ton experiment would ultimately boost the sensitivity to 10^{28} yr corresponding to the $m_{\beta\beta}$ < 10-20 meV range.