First results of GERDA Phase II and consistency with background models

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RC “KI” FSBI “SSC RF ITEP”, Moscow, Russia

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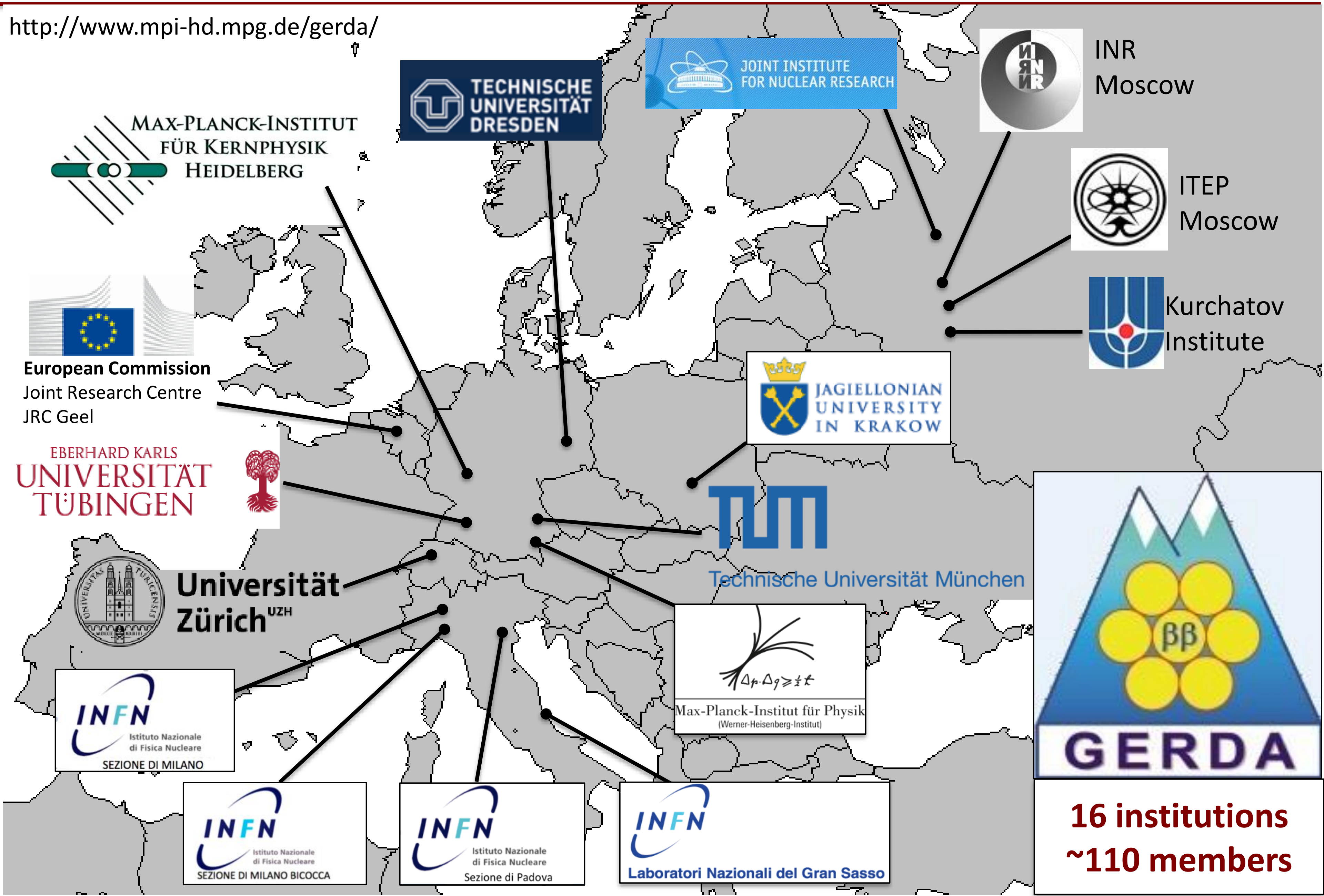
10-14 October 2016, Moscow, Russia

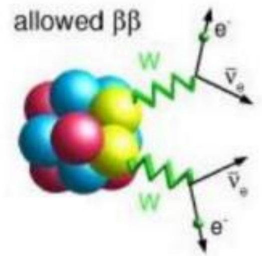
The GERDA Collaboration

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



16 institutions
~110 members

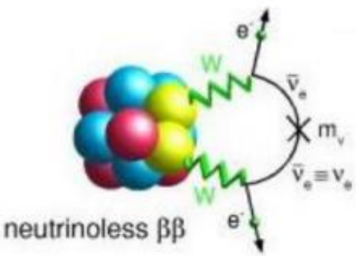
0νββ and 2νββ decay



2νββ decay – allowed by SM: (A,Z) → (A,Z+2) + 2 e^- + 2 $\overline{\nu}_e$ (ΔL=0)

– Signature: β-like spectrum

– Observed in more than 10 isotopes: O($T_{1/2}$)=10^{19}-10^{21} yr



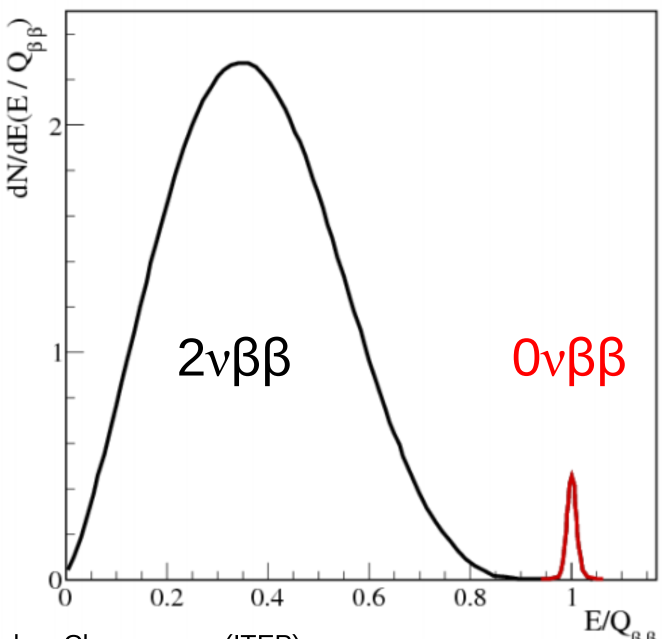
0νββ decay – forbidden by SM: (A,Z) → (A,Z+2) + 2 e^- (ΔL=2)

– Signature: full energy peak at $Q_{\beta\beta}$ (2039 keV for Ge)

– Observation: not found yet

$$\left(T_{1/2}^{0\nu}\right)^{-1} \propto G^{0\nu}(Q,Z) \cdot \left|M^{0\nu}\right|^2 \left\langle m_{\beta\beta} \right\rangle^2$$

- expected decay rate for the 0νββ decay with light neutrino exchange



Experimental sensitivity for an exclusion limit on the 0νββ decay half-life:

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

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

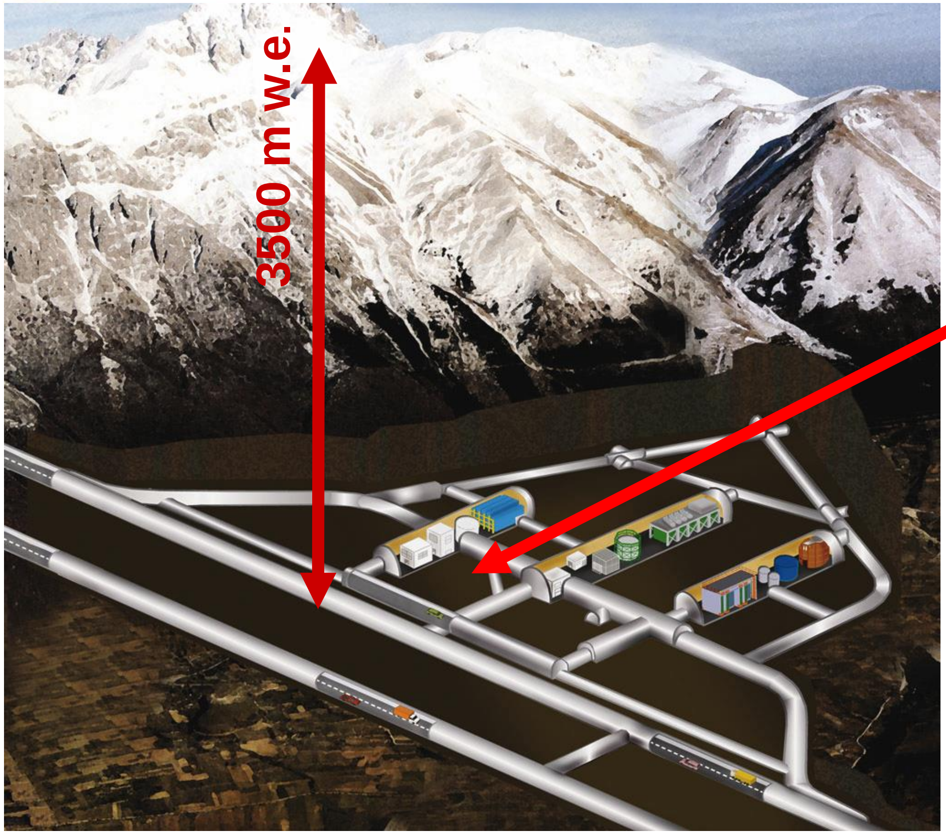
Searching for 0νββ helps to understand:

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

GERDA experiment at LNGS

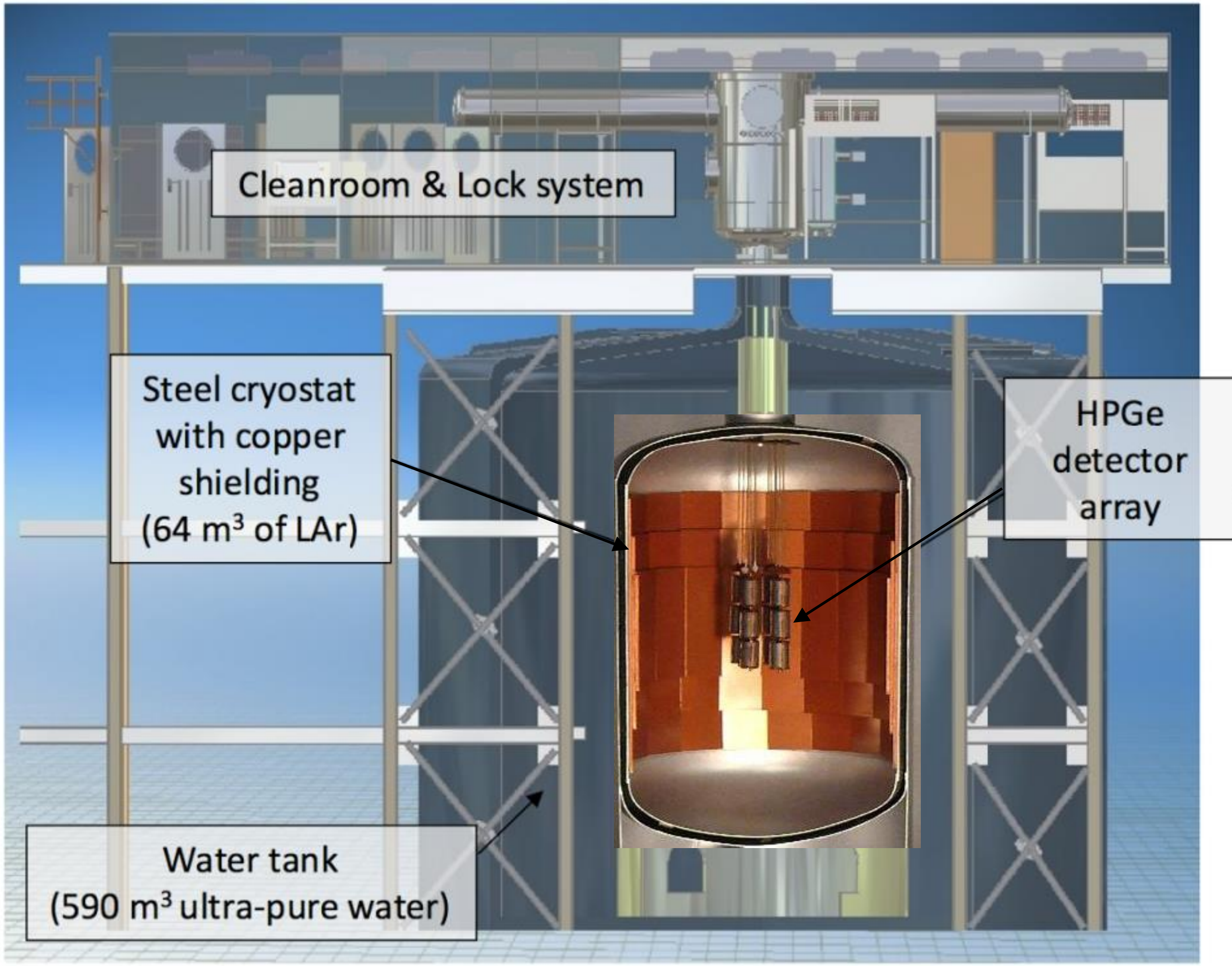
The **GERmanium Detector Array** experiment searches for 0νββ decay in ^{76}Ge using HPGe detectors enriched in ^{76}Ge

Hosted in the Hall A of the Gran Sasso Laboratory, Italy

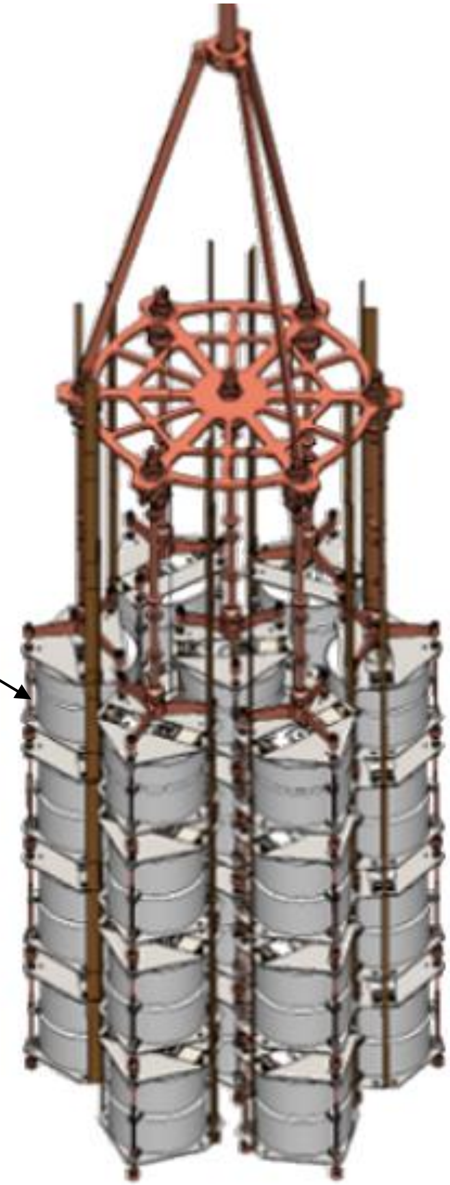


The rock (1500m) overburden is equivalent to 3500 m w.e. This allows to reduce muons (~ 10^6 times) and neutron flux induced by cosmic radiation.

Scheme of GERDA experiment

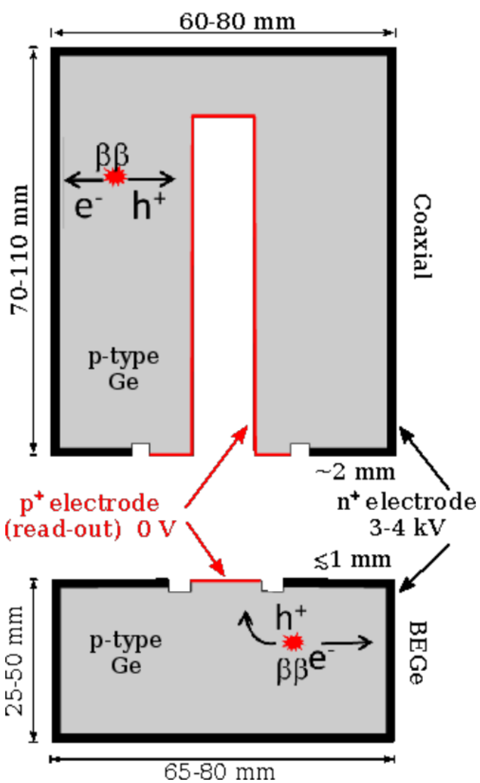


[EPJC 73 (2013) 2330]



GERDA concept

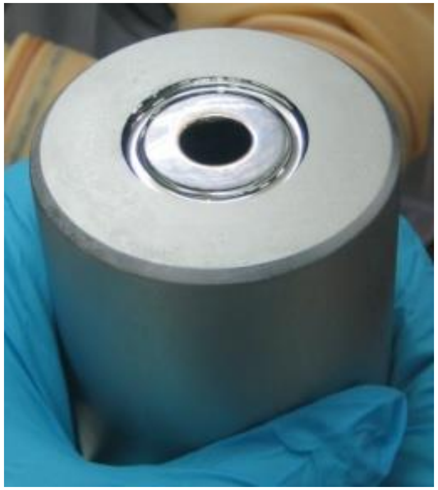
GERDA operates bare High Purity germanium detectors (enriched to ~86% in ^{76}Ge) submersed in liquid Argon (LAr). LAr shields from the radiation and cools down the Ge detectors (80K). The Ge detectors have excellent energy resolution and pulse shape discrimination.



DBD source = Detector

Coaxial* detectors (from HdM, IGEX)

- Enriched + Natural



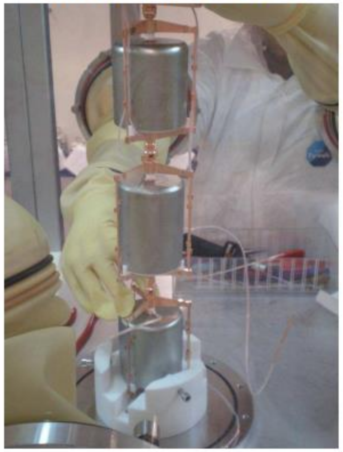
BEGe (Broad Energy Germanium) detectors (produced by Canberra)

- higher energy resolution
- better background events discrimination

*Closed-ended coaxial or semi-coaxial

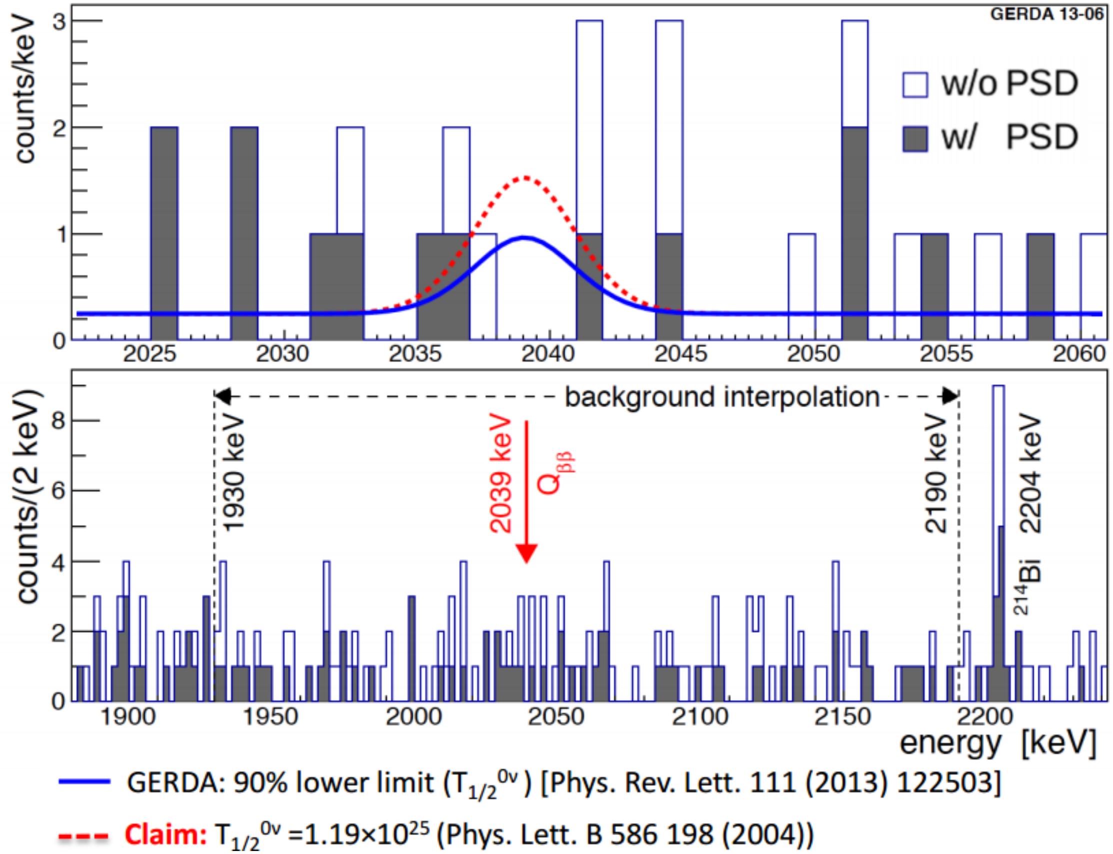
GERDA Phase I results

String with coaxial Ge diodes



String with Broad Energy Ge diodes

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



Nov 2011 – May 2013

- 14.6 kg of ^{76}Ge
- Exposure: 21.6 kg·yr
- Data analysis – fully **blinded**

ROI: $Q_{\beta\beta}$±5keV

- N_{exp} = 2.0±0.3
- N_{obs} = 3

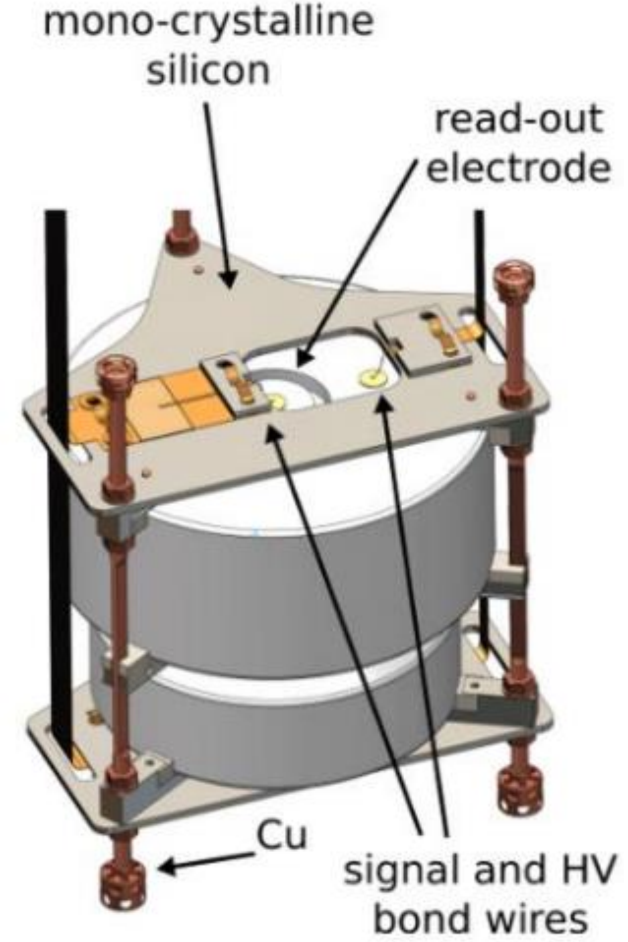
- No $0\nu\beta\beta$ signal at $Q_{\beta\beta}$
- BI: 0.01 cts/(keV·kg·yr) at $Q_{\beta\beta}$
- $T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}$ yr (90% C.L.)

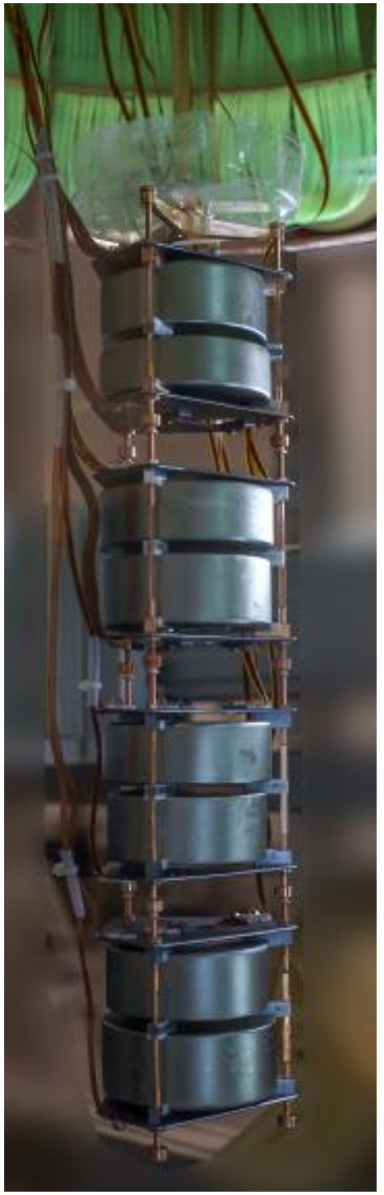
GERDA Phase II preparations

To increase sensitivity of the experiment:

- Increase mass: 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)):

- Pulse Shape Discrimination (PSD) for BEGe and Coax detectors.
- LAr light scintillation veto.
- Cleaner components:
  - New low radioactive holders
  - New contacting/electronics
  - New HV and signal cables

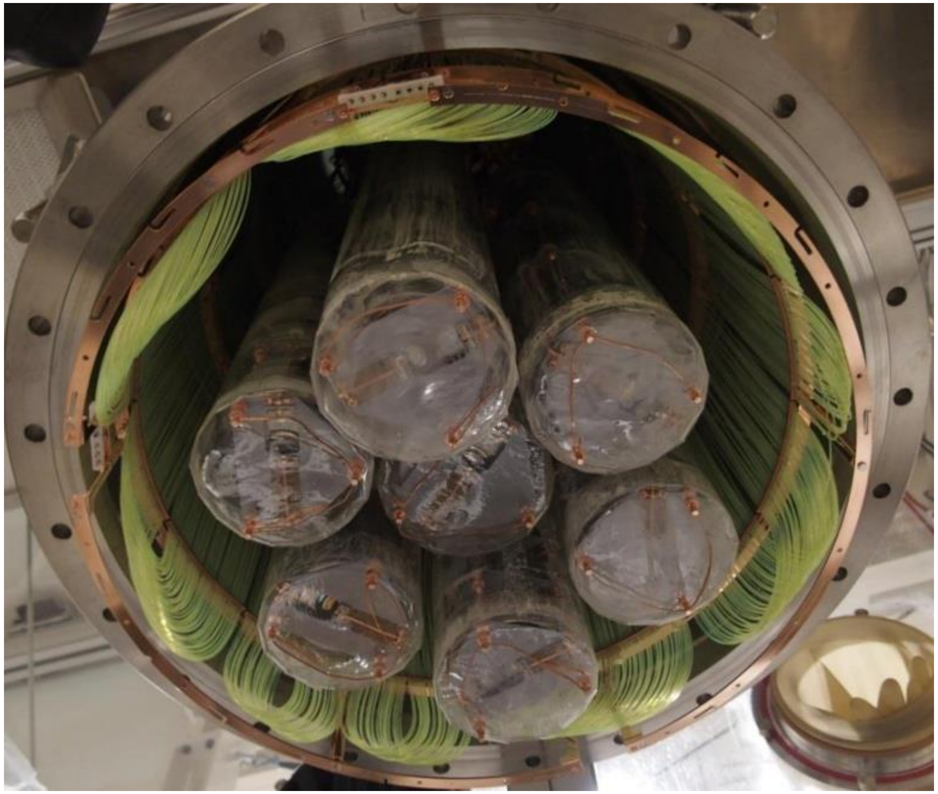


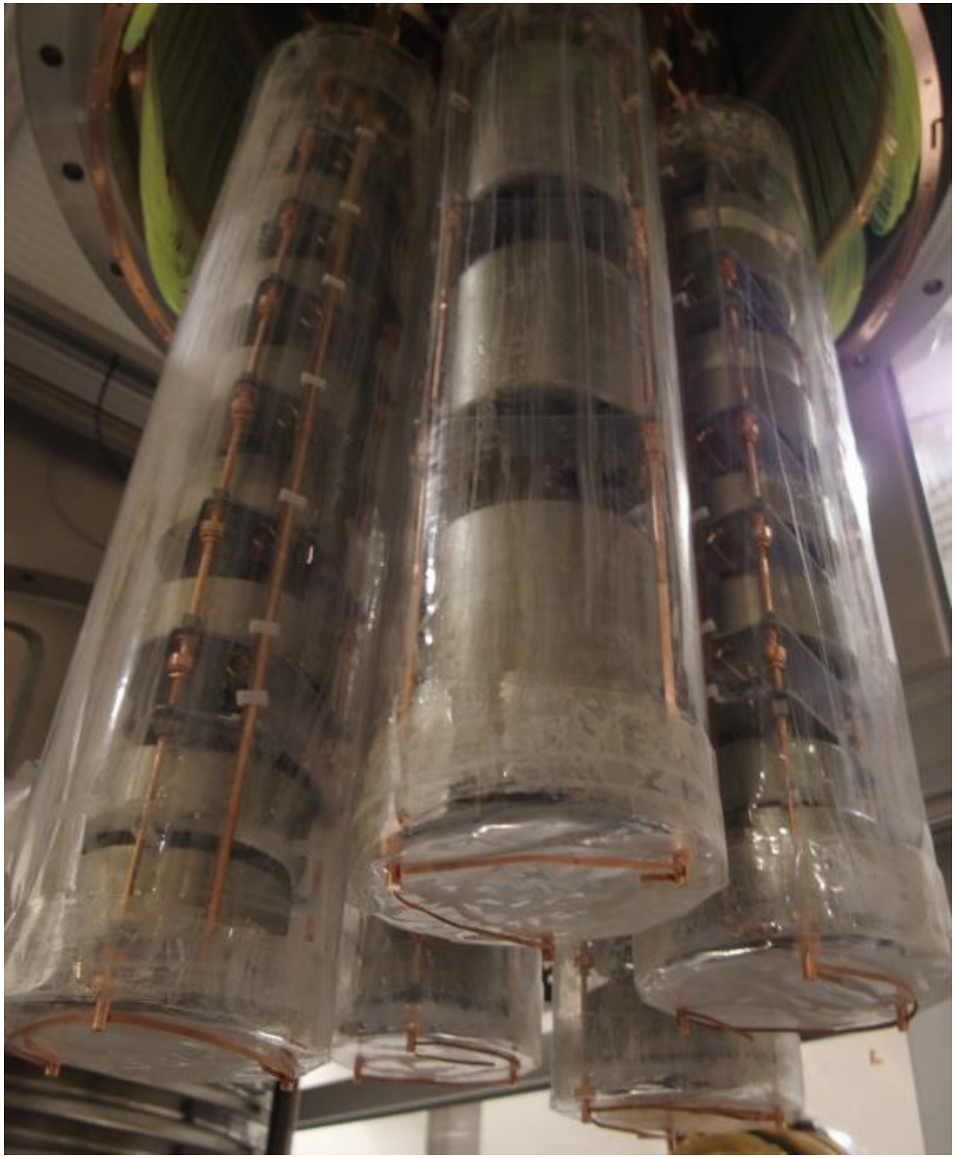


GERDA Phase II configuration

- Deployed in December 2015
- 7 strings, 40 detectors
- 30 enriched BEGe (20 kg)
- 7 enriched coax (15.8 kg)
- 3 natural coax (7.6 kg)

Total: 35.8 kg of enriched Ge

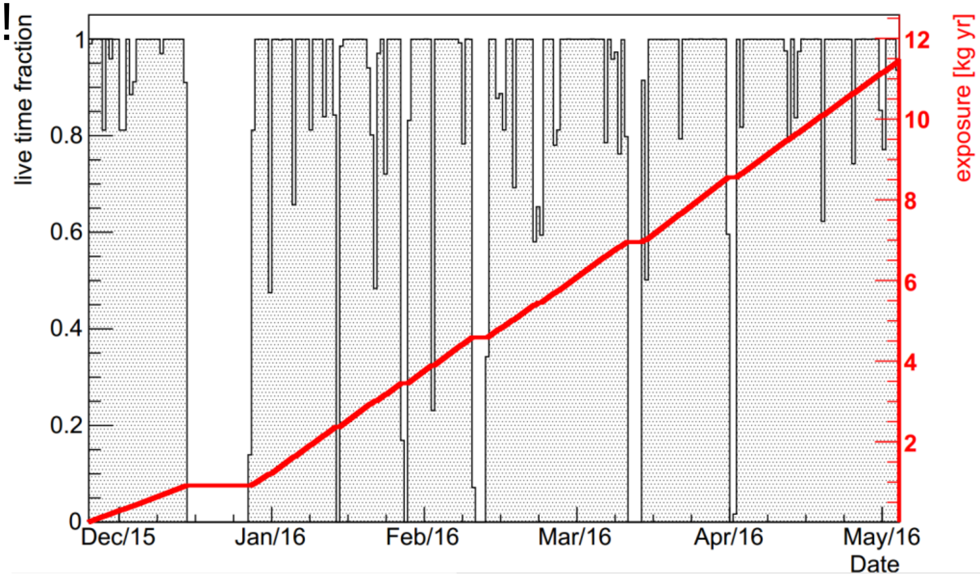




Data taking

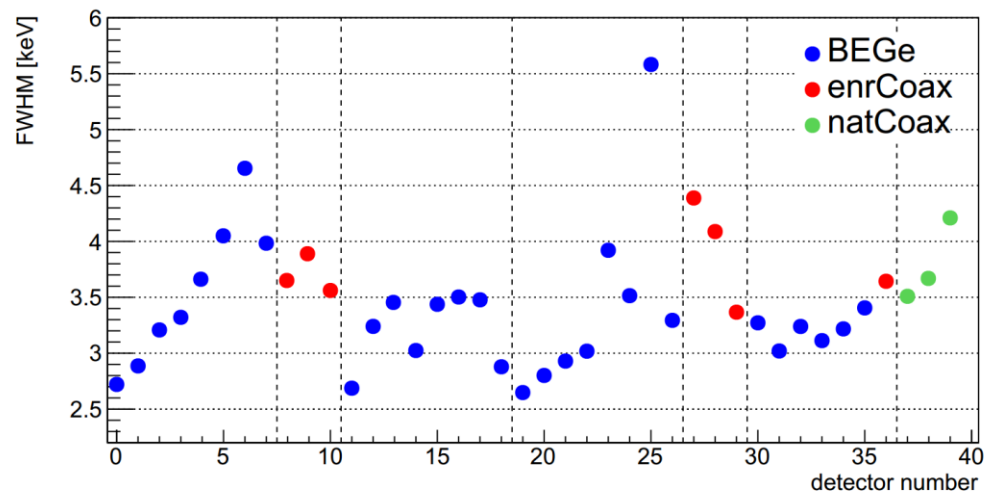
All Ge detectors + LAr veto are working!

- Dec 2015 - May 2016
- 82% average duty cycle
- exposure used for analysis:
  - 5.8 kg·yr for enriched BEGe
  - 5.0 kg·yr for enriched coax
- weekly calibration runs with ^{228}Th
- blinding window $Q_{\beta\beta} \pm 25$ keV



Performance on full physics data set (10.8 kg·yr):

dataset	energy resolution (FWHM at $Q_{\beta\beta}$)
coaxial	4.0 (2) keV
BEGe	3.0 (2) keV



Background topology and rejection

Signal = ββ events

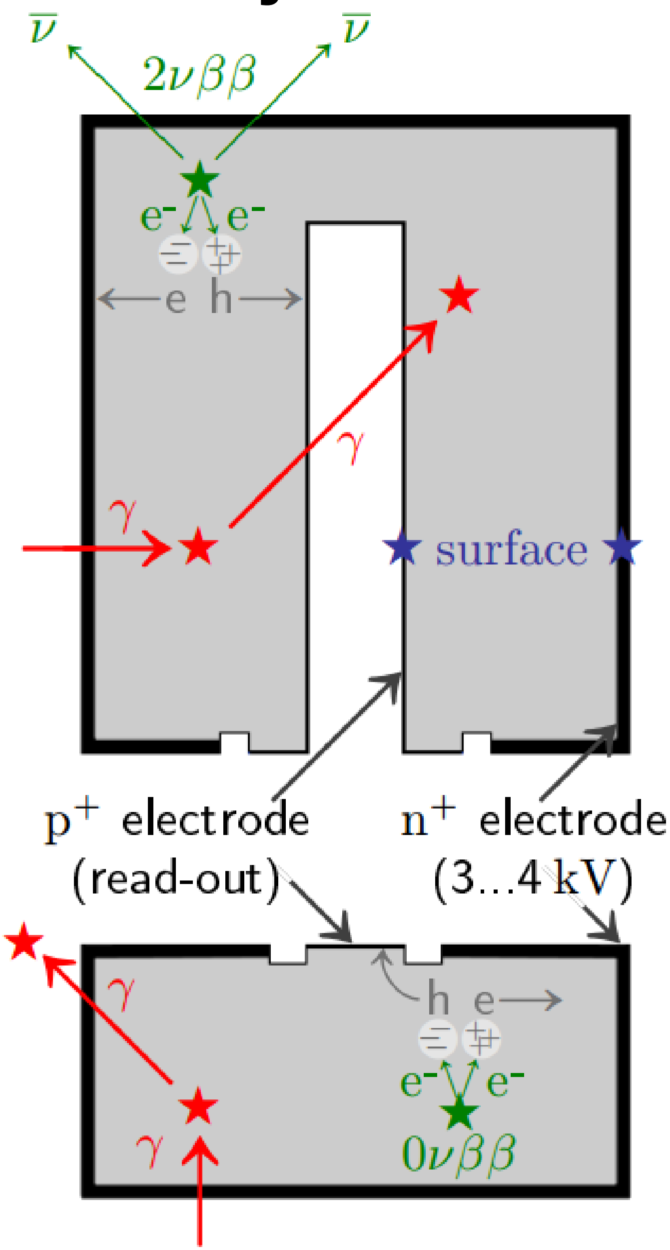
- local energy deposition within ≈1mm in only one detector (SSE)

Background = γ events

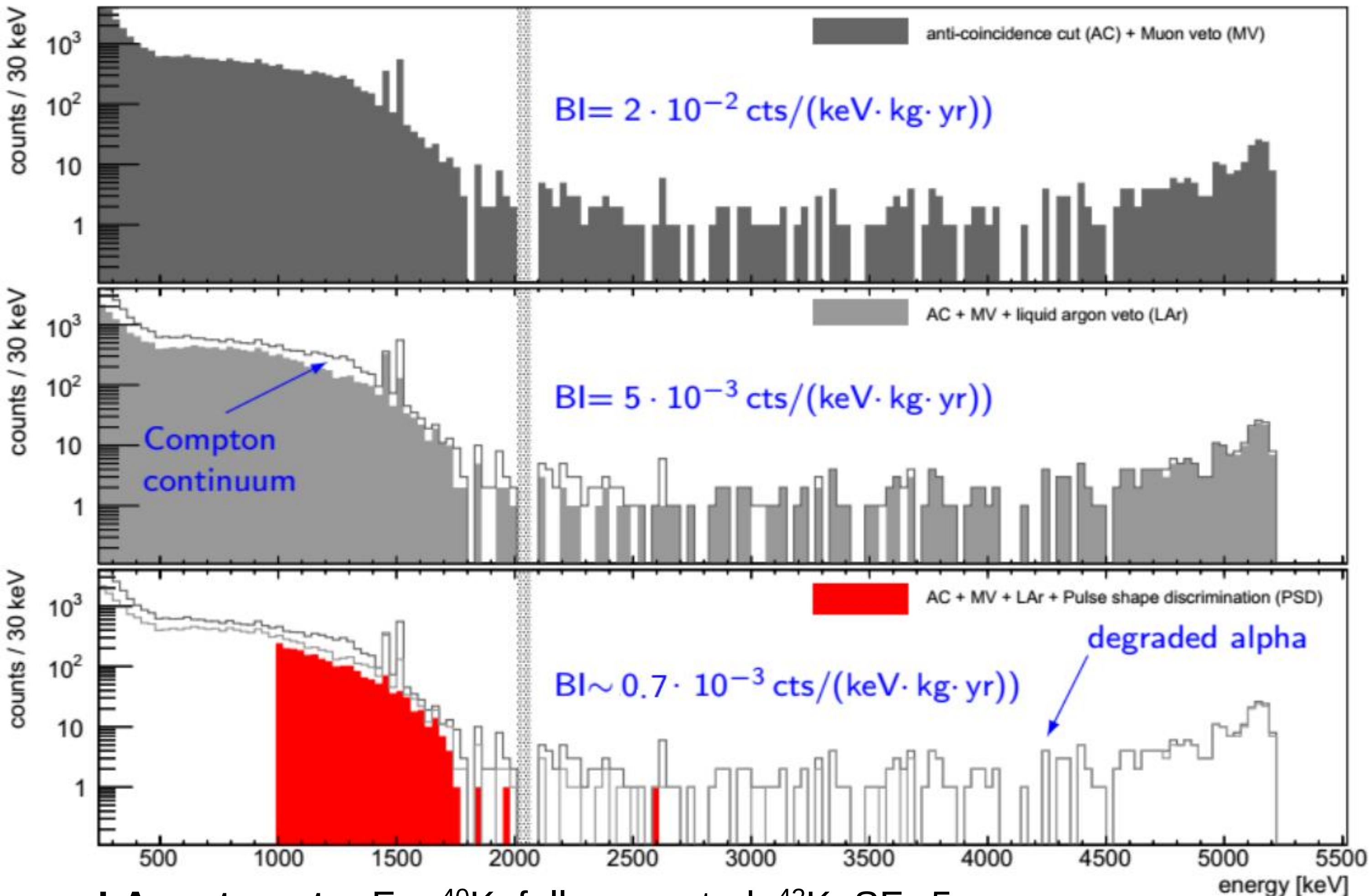
- multiple energy deposition in one detector (MSE)
  - ▶ PSD
- events with coincident energy deposition in the LAr
  - ▶ LAr veto (new in Phase II)
- energy deposition in multiple detectors
  - ▶ Anti-coincidence cut

Surface = α and β events

- Energy deposited on/close by detector surface contacts
  - ▶ PSD: fast (p+) and slow (n+) rising signals



Background suppression - BEGe



LAr veto cut: • For ^{40}K: fully accepted; ^{42}K: SF~5

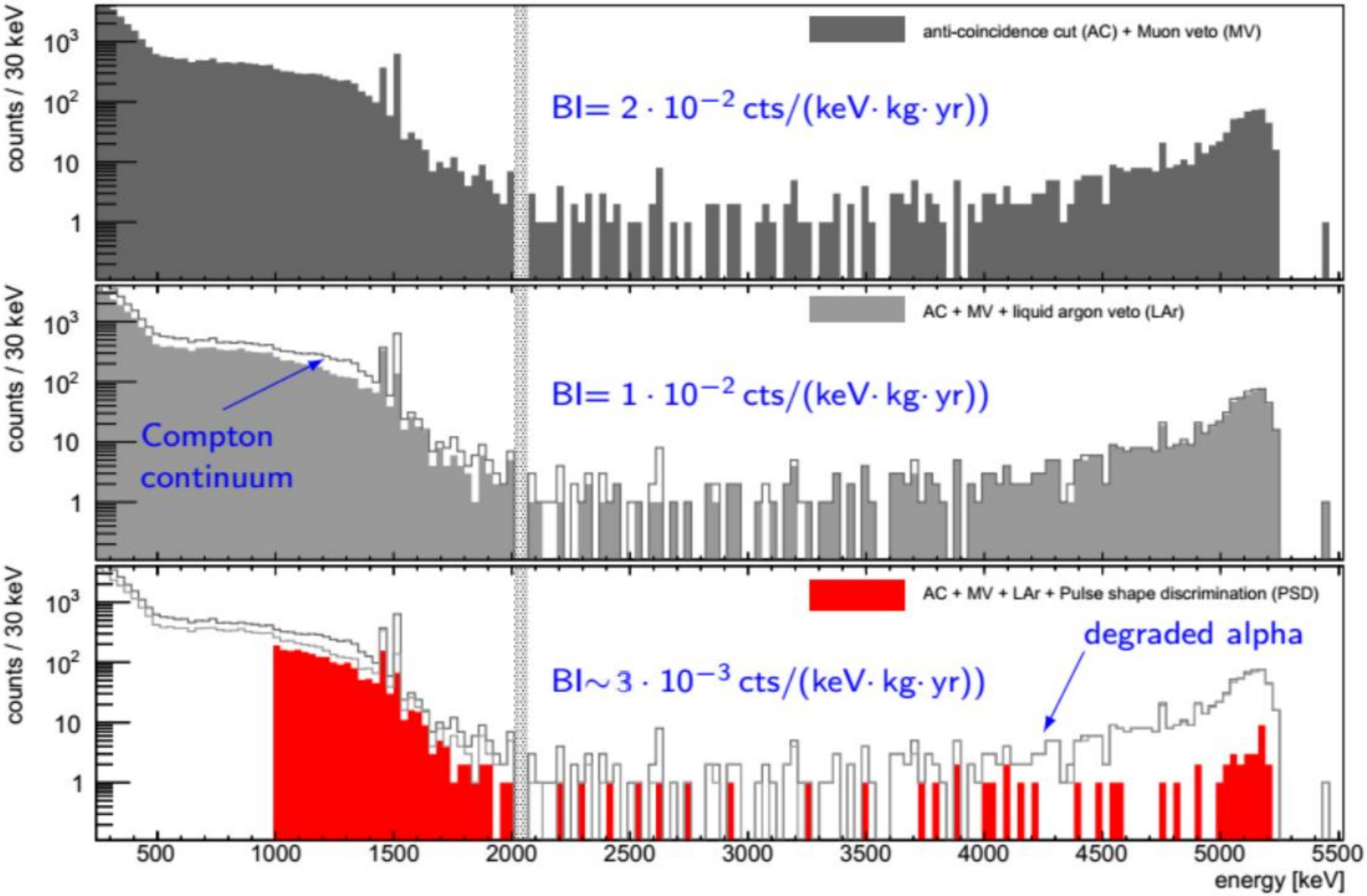
• Below 2 MeV: basically only 2νββ spectrum

• In 1839-2239 keV: survival fraction = ~1/3

Pulse shape: • Events in ROI: signal accep. 87.3±0.9 %, Bg reject. 80%

• α events: very efficient rejection

Background suppression - Coaxial



LAr veto cut: • In 1839-2239 keV: survival fraction ~1/2

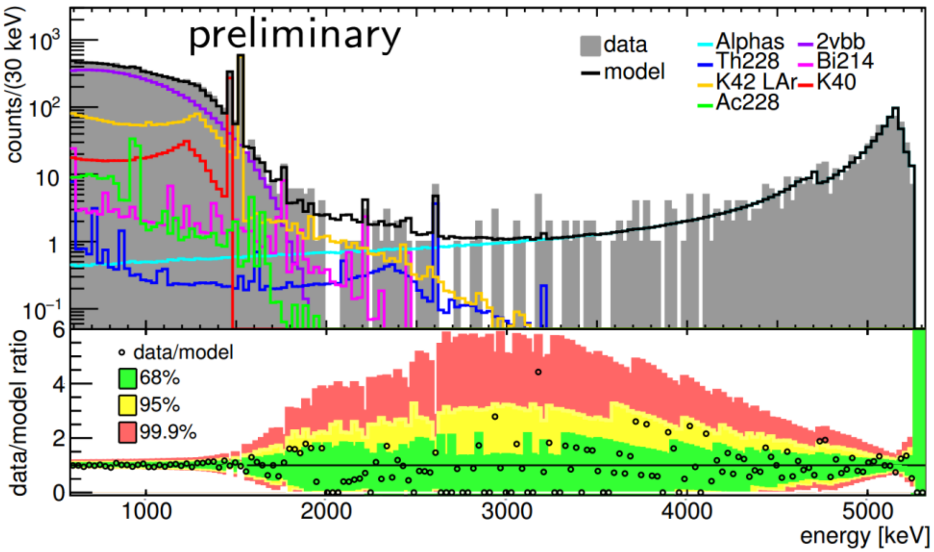
Pulse shape: • Multi-site events: rejected via artificial neural network (ANN) + projective Likelihood: ε_{MSE} = (80±9)% 0νββ acceptance

• α events: rejected via ANN: ε_{α} = (96±1)% 0νββ acceptance

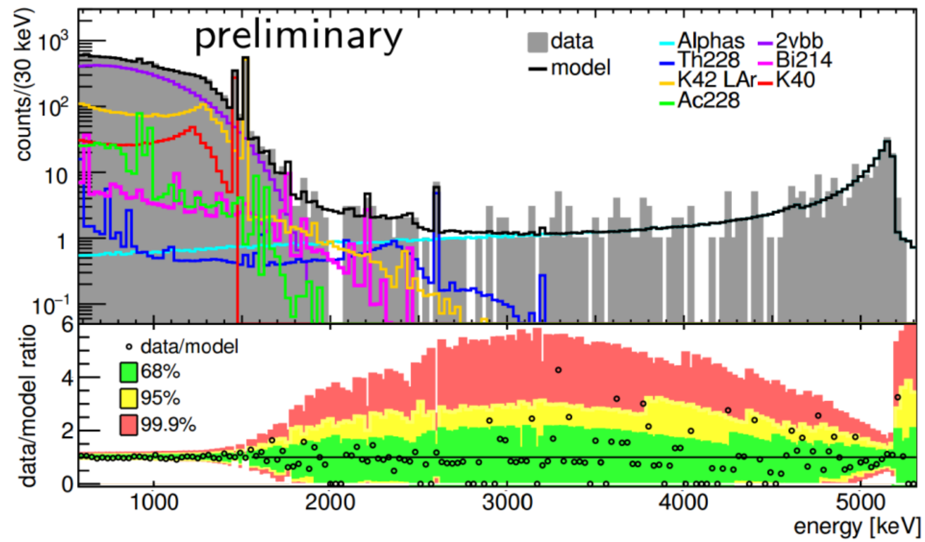
• **Total eff**.: $\varepsilon_{PSD} = \varepsilon_{MSE} \cdot \varepsilon_{\alpha}$ = (77±9)%, while bg. rejected at 65%

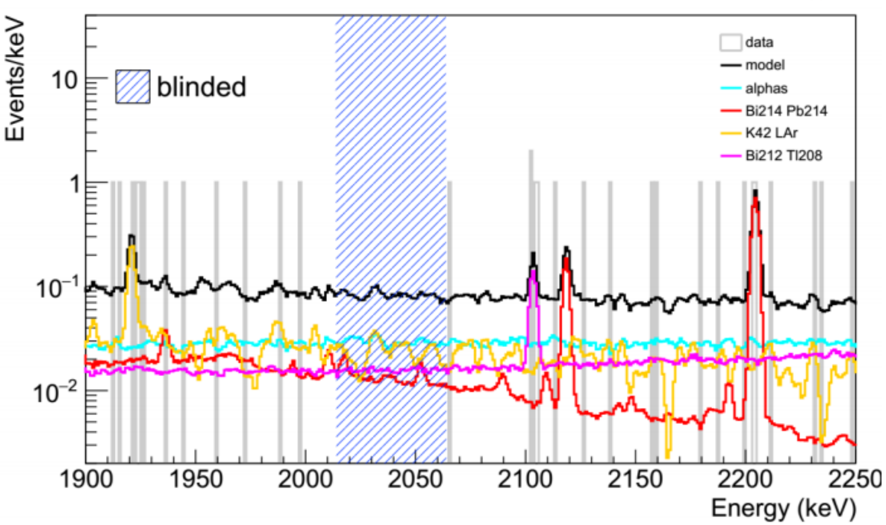
Background modeling before LAr veto and PSD

Coaxial



BEGe





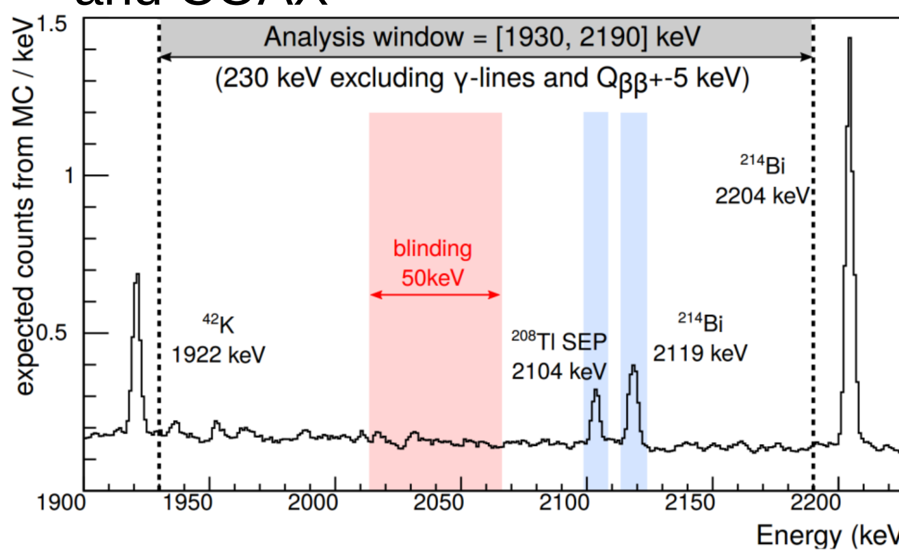
- Preliminary simulation of the background well describe observed data.
- Same isotopes like in Phase I
- Th/Ra contributions consistent with screening results
- Main background components before PSD and LAr:
  - α from ^{210}Po, ^{226}Ra
  - β from ^{42}K
  - γ from ^{214}Bi, ^{208}Tl

Unblinding

GERDA collaboration meeting at Ringberg 17 June 2016: unblinding data in $Q_{\beta\beta}$±25 keV

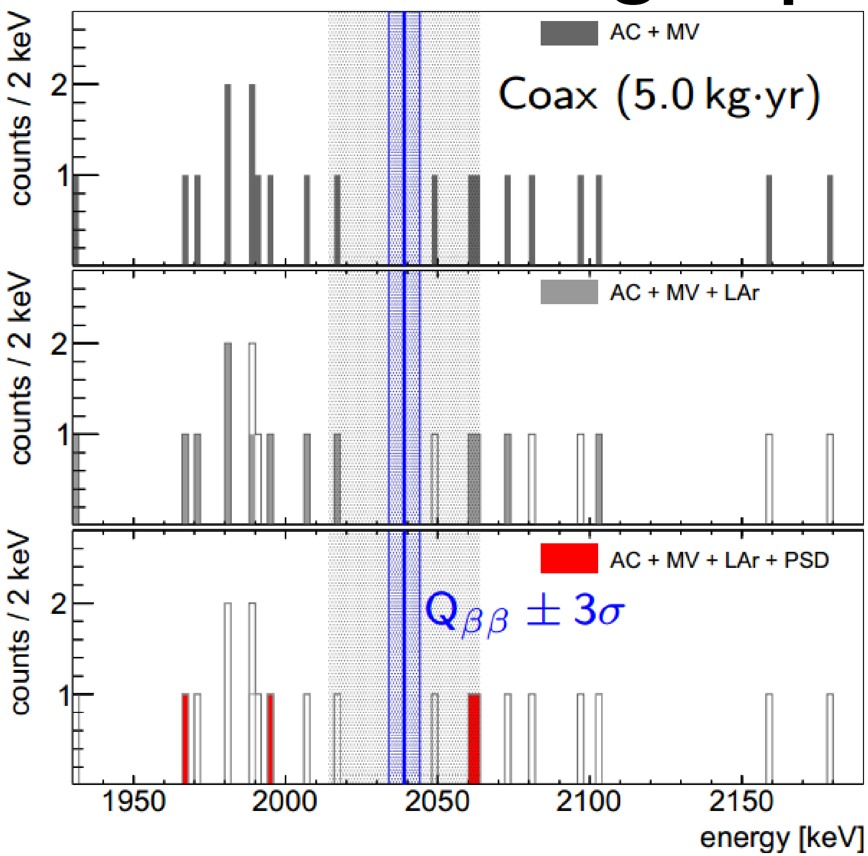
“Freeze” steps prior unblinding:

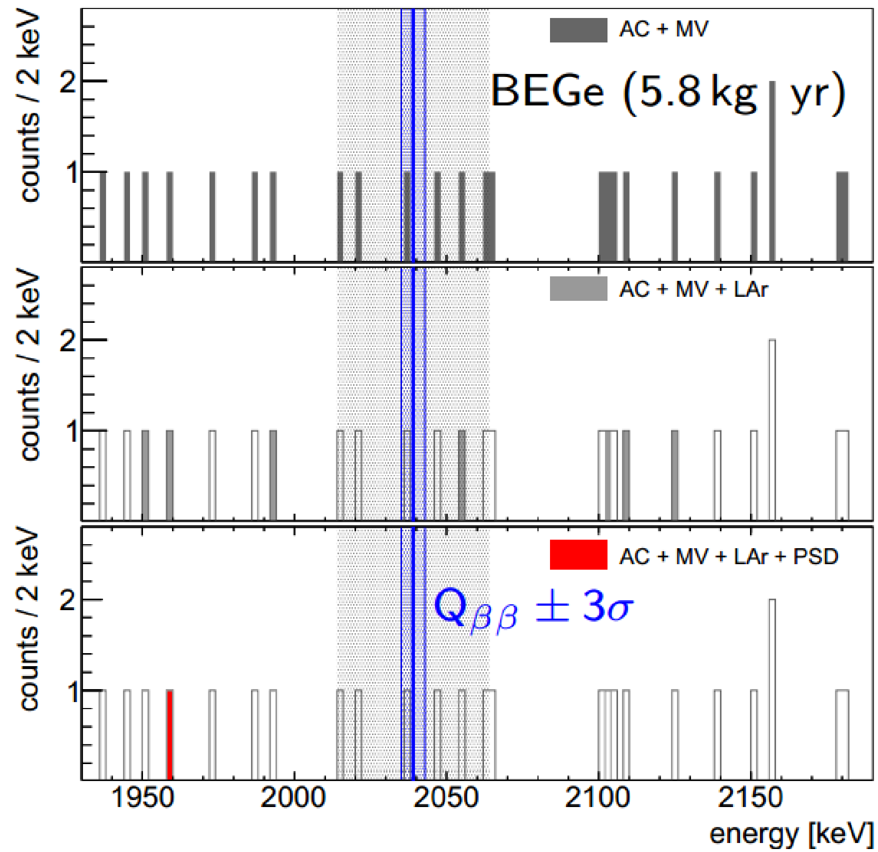
- analysis cuts
- data period
- background model
- LAr veto and PSD cuts for BEGe and COAX



Fixation and coordination of statistical methods

Unblinding: spectrum around $Q_{\beta\beta}$





		Coax	BEGe
cts expected from bkg	$Q_{\beta\beta}\pm25$ keV	0.8	0.3
	1930-2190 keV	3.6	1.2
cts observed	$Q_{\beta\beta}\pm25$ keV:	2	0
	1930-2190 keV:	4	1
background index	**1930-2190 keV**	**$35\cdot10^{-4}$**	**$7.4\cdot10^{-4}$ cts/keV·kg·yr**

Statistical analysis

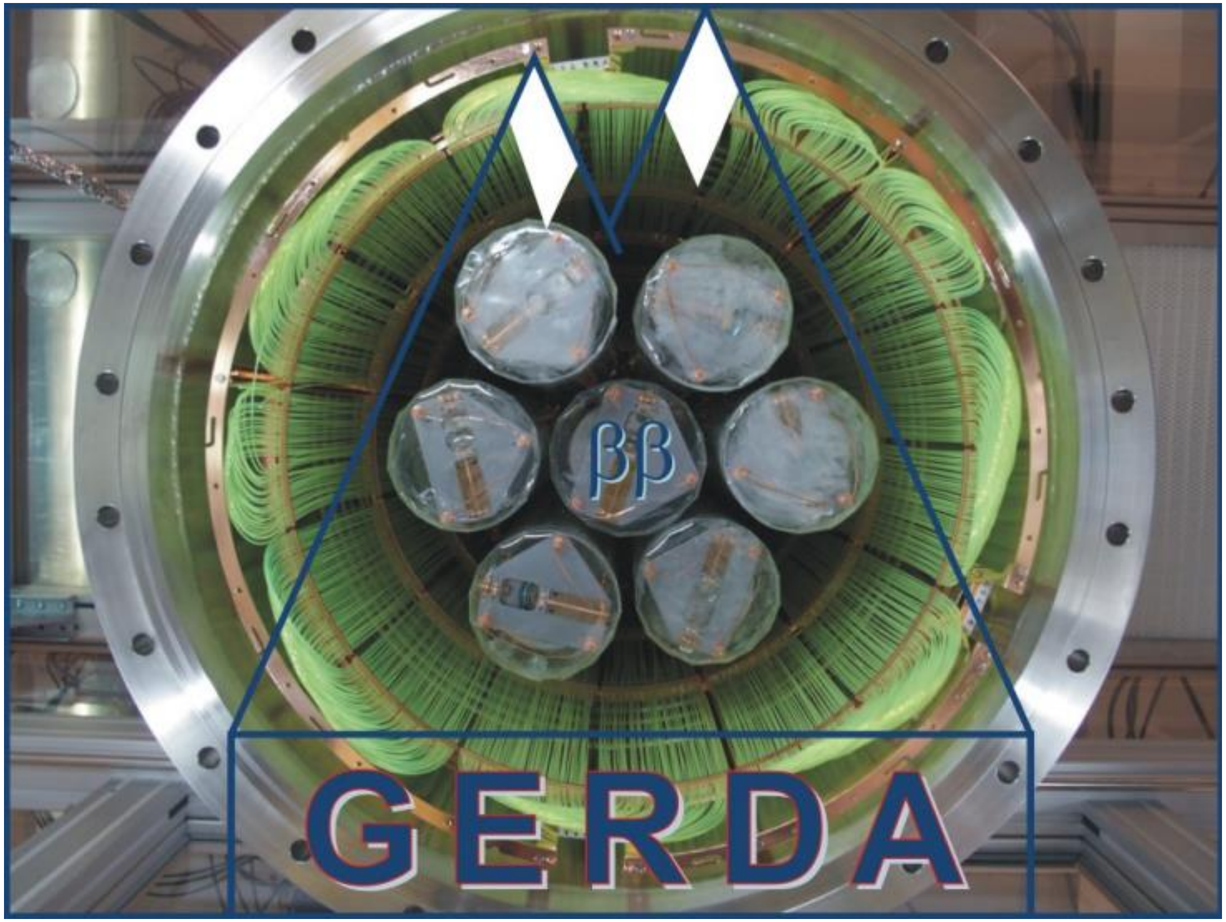
data set		exposure [kg·yr]	signal eff	background [cts/(keV· kg· yr)]	resolution [FWHM]
Phase I	golden	17.9	0.57 (3)	$11 \pm 2 \cdot 10^{-3}$	4.3 (1)
Phase I	silver	1.3	0.57 (3)	$30 \pm 10 \cdot 10^{-3}$	4.3 (1)
Phase I	BEGe	2.4	0.66 (2)	$5^{+4}_{-3} \cdot 10^{-3}$	2.7 (2)
Phase I	extra	1.9	0.58 (4)	$5^{+4}_{-3} \cdot 10^{-3}$	4.2 (2)
Phase II	coaxial	5.0	0.51 (7)	$35^{+21}_{-15} \cdot 10^{-4}$	4.0 (2)
Phase II	BEGe	5.8	0.60 (2)	$7^{+11}_{-5} \cdot 10^{-4}$	3.0 (2)

	profile likelihood 2-side test-stat	Bayesian flat prior on cts
$0\nu\beta\beta$ cts best fit value [cts]	0	0
$T_{1/2}^{0\nu}$ lower limit [10^{25} yr]	>5.2 (90% CL)	>3.5 (90% CI)
$T_{1/2}^{0\nu}$ median sensitivity [10^{25} yr]	>4.0 (90% CL)	>3.0 (90% CI)

GERDA Phase II summary

- GERDA Phase II successfully started in December 2015.
- Lowest background in ROI ever achieved in $0\nu\beta\beta$ experiments:
  – for Coax detectors: $35^{+21}_{-15} \cdot 10^{-4}$ cts/(kg·keV·yr)
  – for BEGe detectors: $7^{+11}_{-5} \cdot 10^{-4}$ cts/(kg·keV·yr)
- Such BI opens the way for the future experiments
- Combined Phase I+II sensitivity:
  – $T^{0\nu}_{1/2} > 4.0 \cdot 10^{25}$ yr (90% C.L.)
- Blind analysis, no $0\nu\beta\beta$ signal at $Q_{\beta\beta}$:
  – $T^{0\nu}_{1/2} > 5.2 \cdot 10^{25}$ yr (90% C.L.)
- Data taking of Phase II is continued. More results with higher sensitivity is expected in coming years.

GERDA Phase II is the first background free double beta experiment

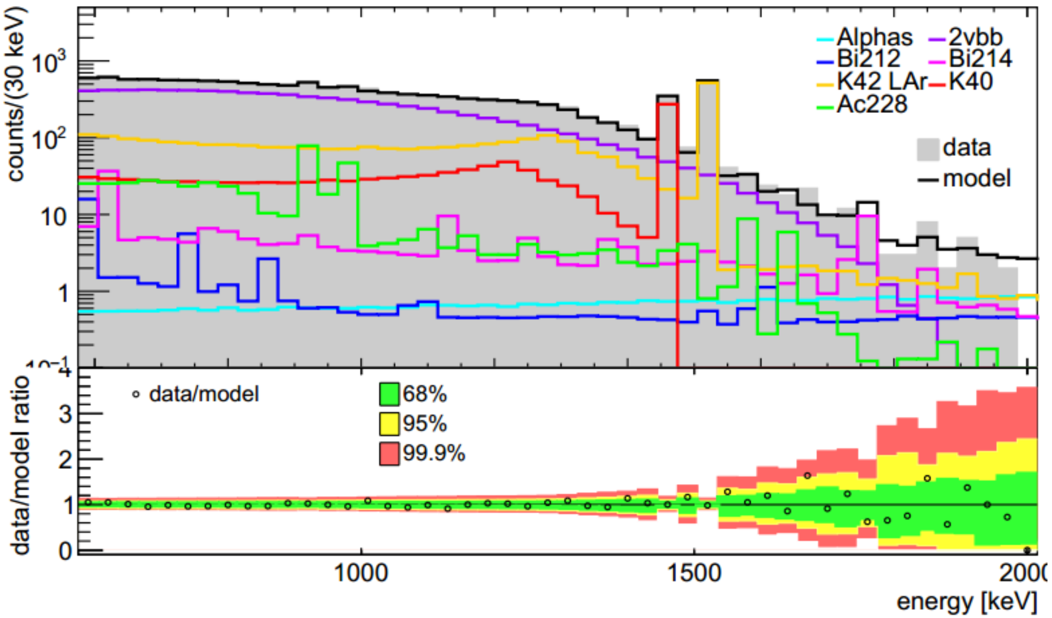


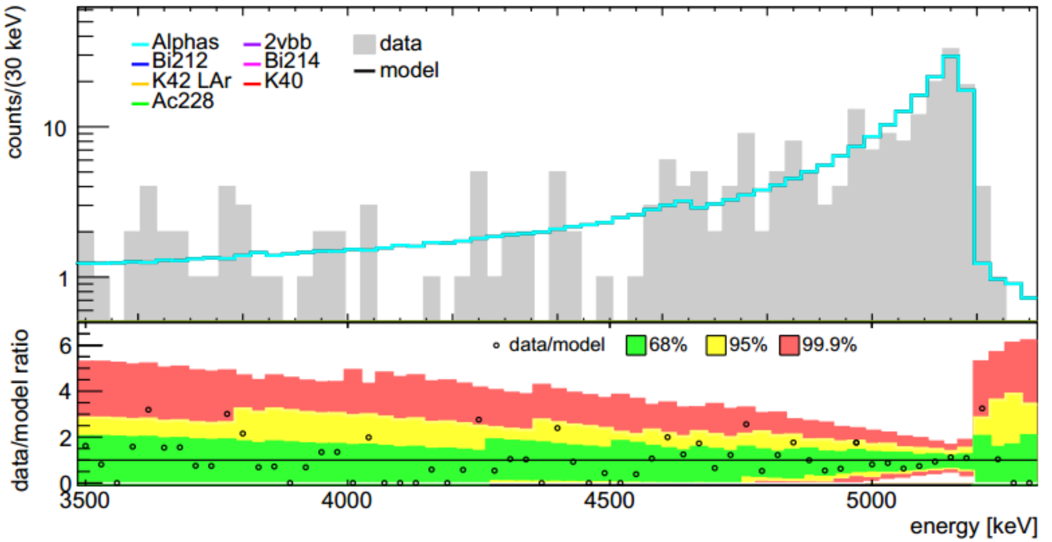
THANK YOU FOR YOUR ATTENTION !

Andrey Chernogorov (ITEP)

Back up slides

Preliminary background model BEGe Phase II





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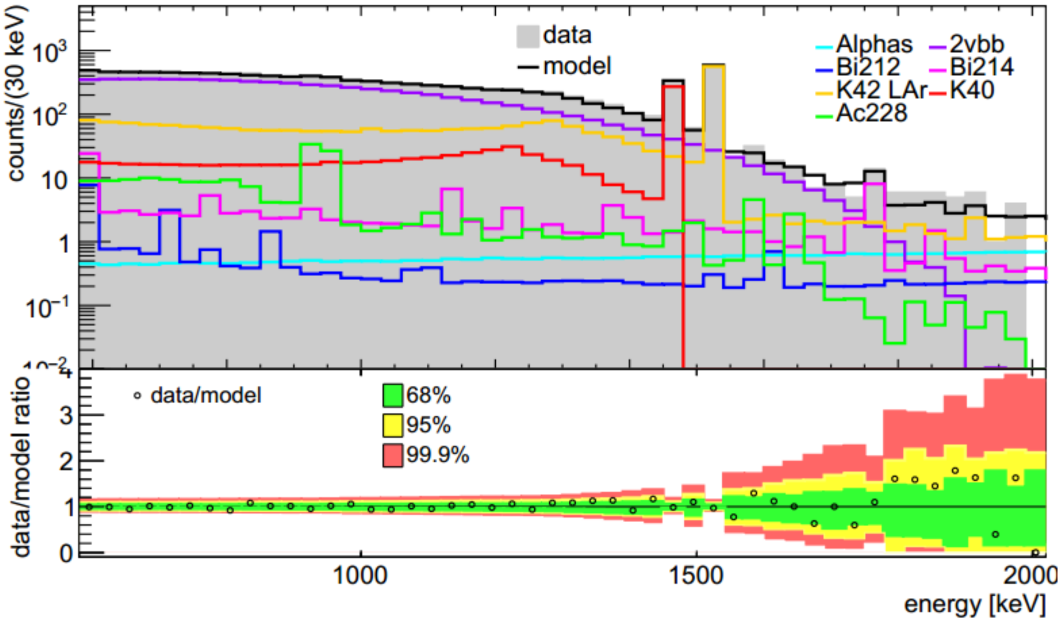
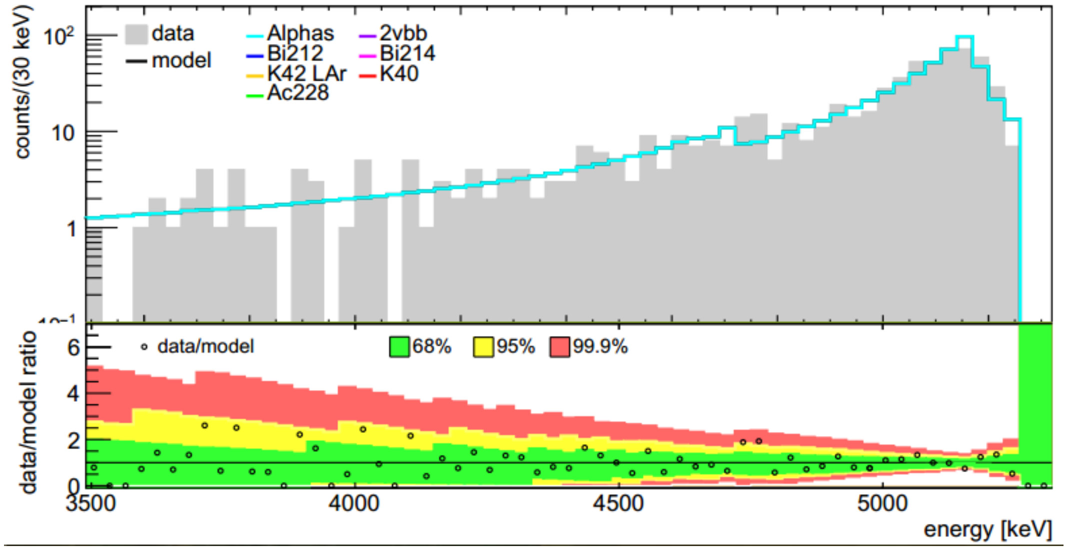
Preliminary background model Coax Phase II





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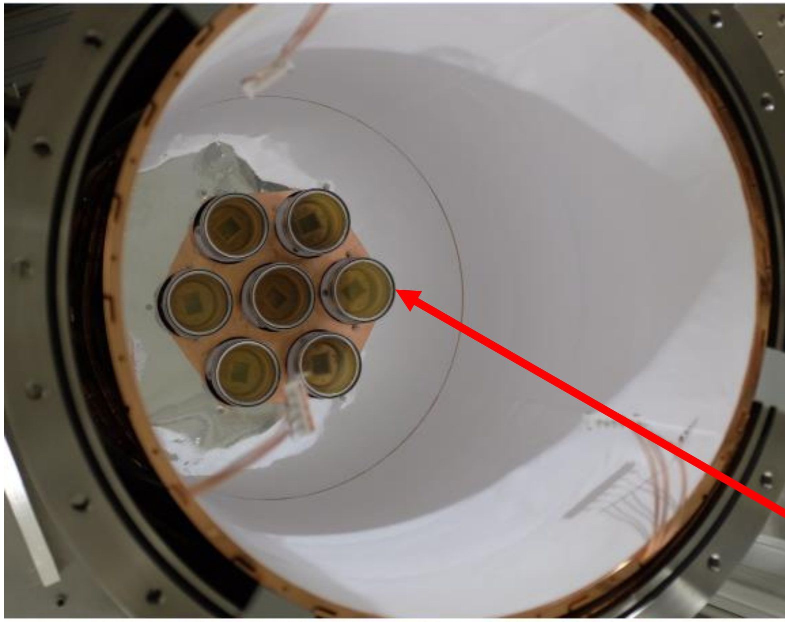
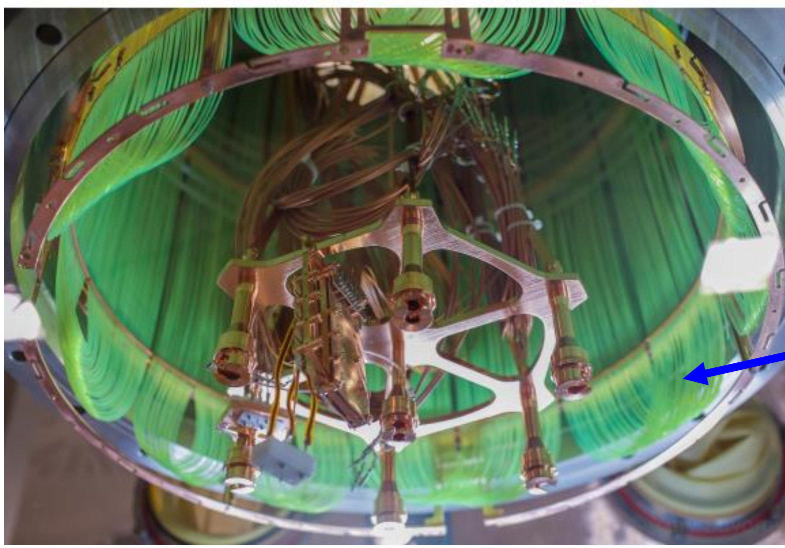
LAr veto light instrumentation

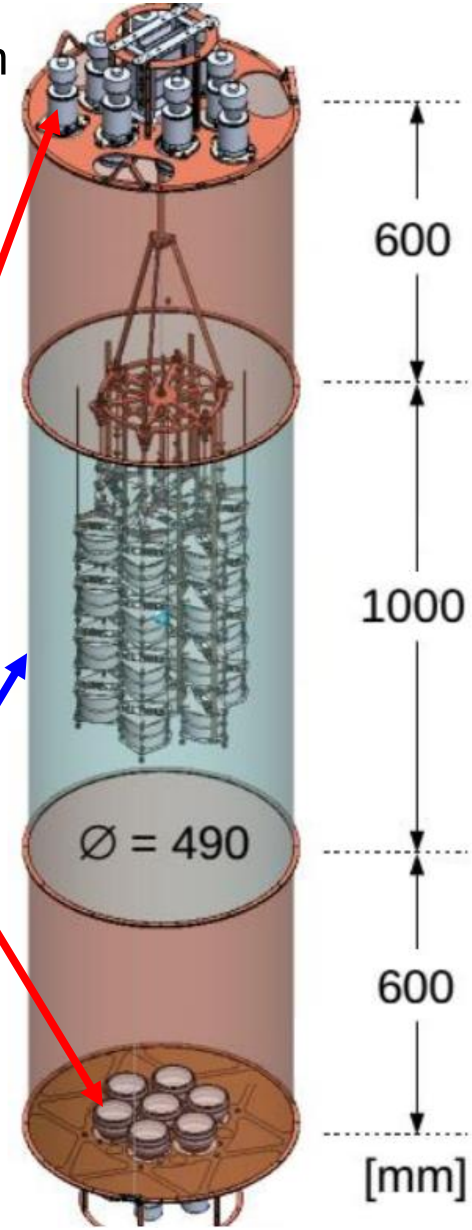




LAr scintillation veto works in the coincidence with Ge detectors allowing to suppress background events which deposit energy in LAr.

16 PMTs
(9 top/ 7 btm)

800m fibers
coated with WLS
+ 90 SiPMs



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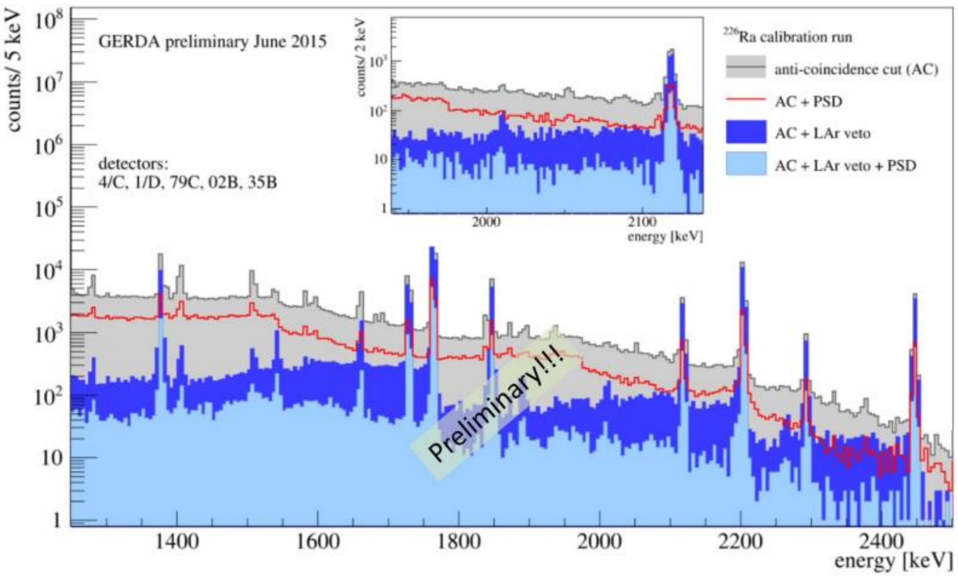
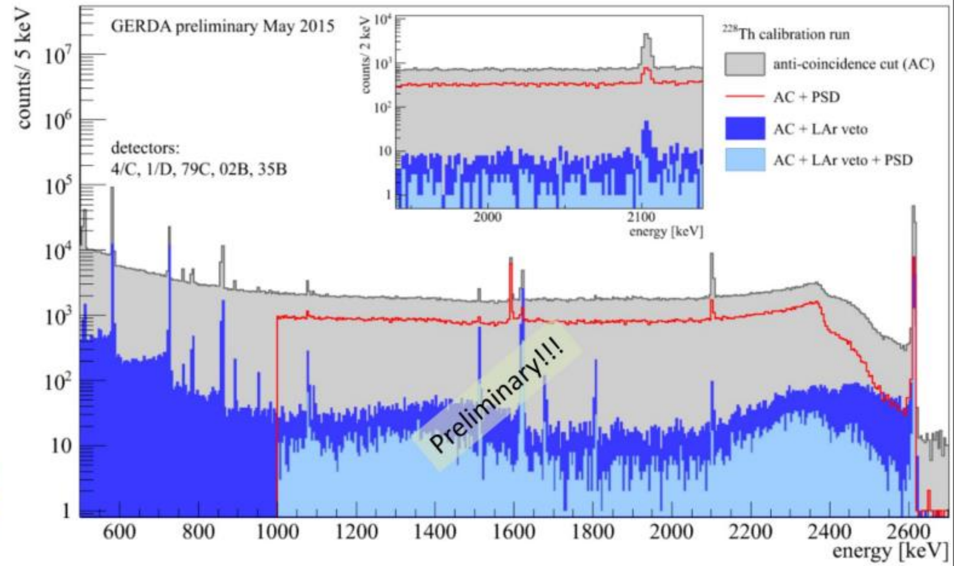
LAr veto performance

^{226}Ra calibration source



^{228}Th calibration source

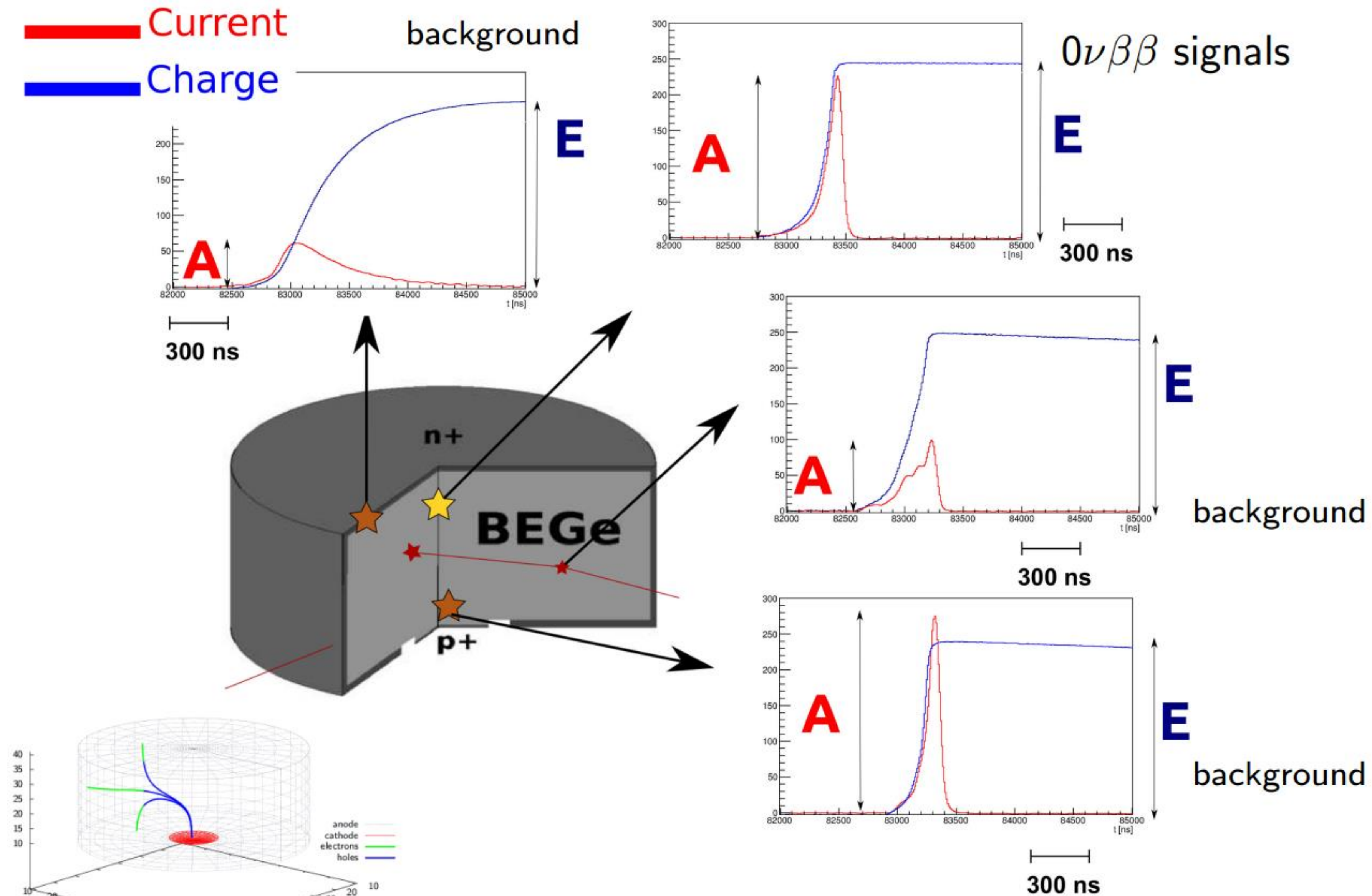


	^{226}Ra	^{228}Th
veto suppression factor	5.1±0.2	85±3
combined with pulse shape & anti-coincidence	25±2.2	390±28

>5 background suppresion for ^{226}Ra & ^{228}Th by LAr veto

Suppression factors depends on isotopes, location and detector configuration.

PSD: BEGe



Current and Charge Amplitudes Ration (A/E)

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