GERDA PHASE II
FIRST RESULTS

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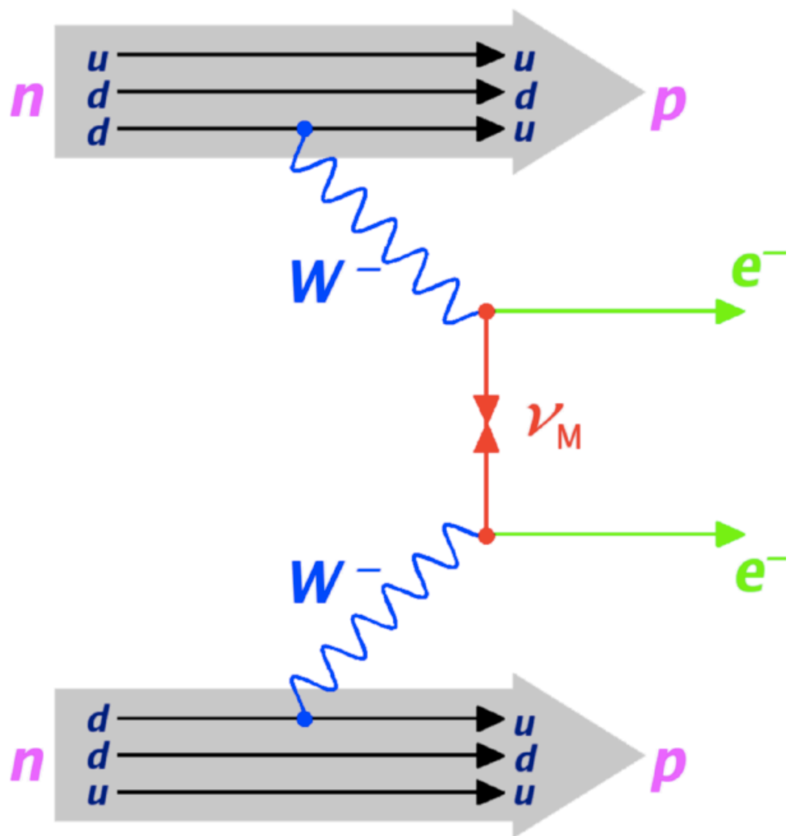
Outline

- Neutrinoless Double Beta ($0\nu\beta\beta$) decay
- GERDA
- Summary of GERDA Phase I
- GERDA Phase II
  - Phase II Upgrade
  - Configuration of GERDA Phase II
  - Performances: energy scale and resolution
  - Background
  - Liquid argon veto and pulse shape discrimination
  - Unblinding and first results
- Conclusions and Summary

Neutrinoless Double Beta (0νββ) decay

Powerful method to study the unknown neutrino properties



Observation of 0νββ decay implies:

- the neutrino ν is a Majorana particle
- the lepton number can be violated (L = 2)
- it is possible to determine the ν absolute mass (nuclear model dependent)

Half life of 0νββ (in case of light Majorana neutrino exchange):

effective neutrino mass

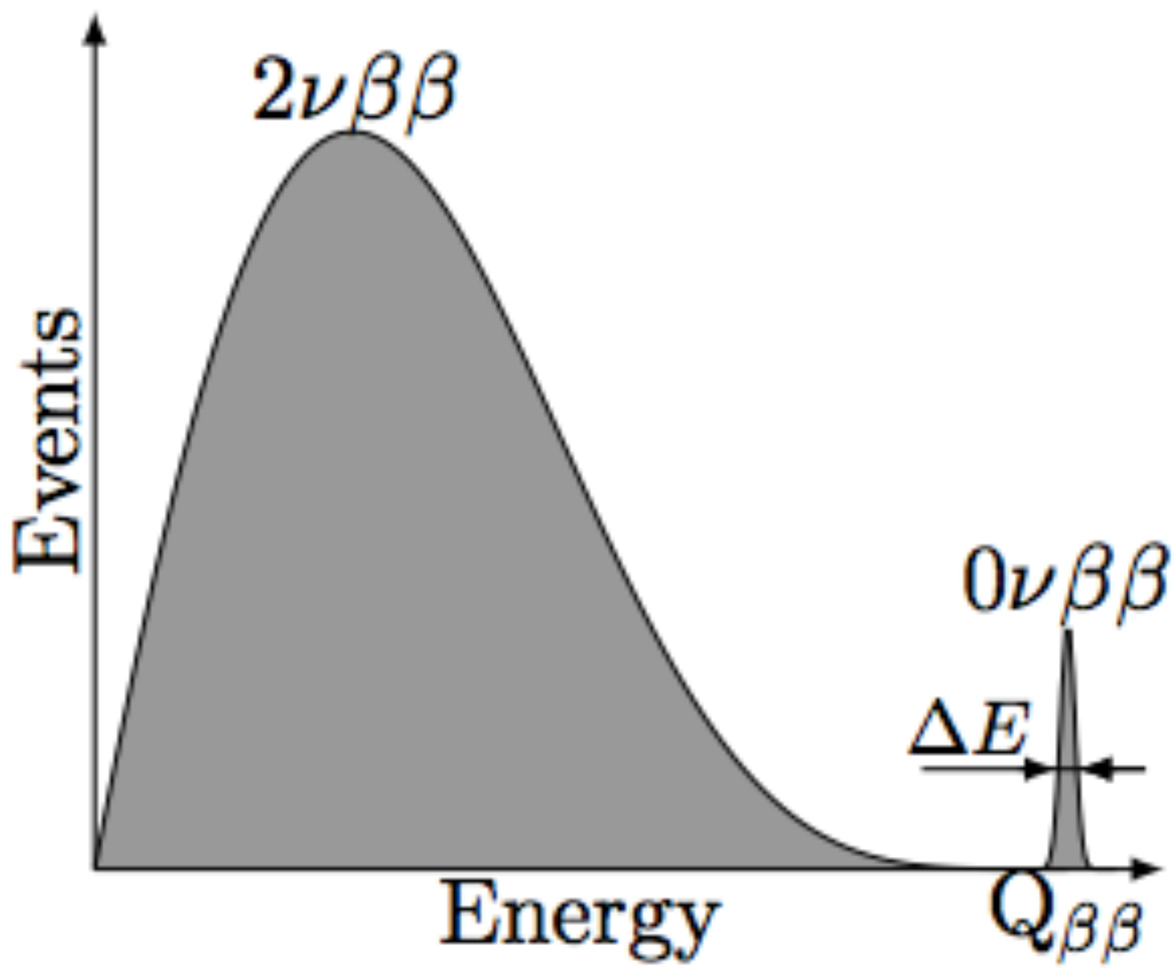
$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu} |M_{0\nu}|^2 \left(\frac{m_{\beta\beta}}{m_e}\right)^2$$

phase space integral

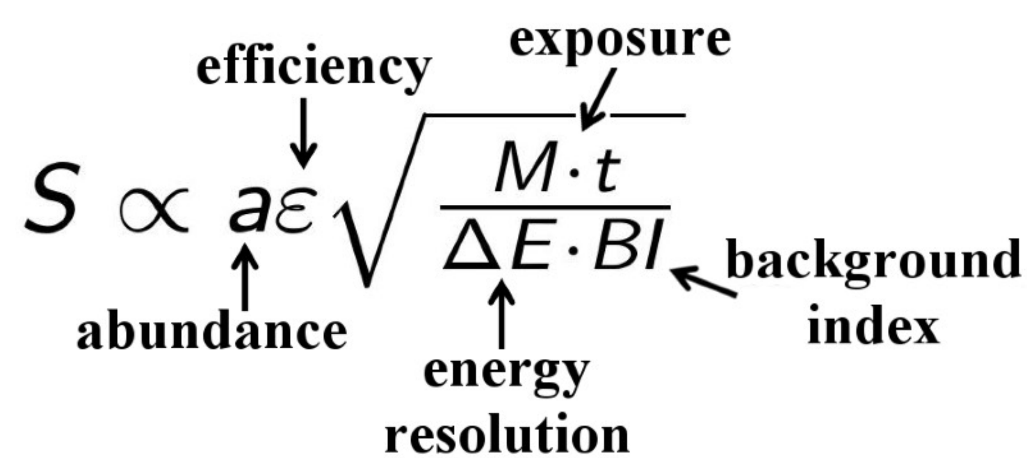
nuclear matrix element

Search for 0νββ decay

Signature is a sharp peak at Q-value of the decay **(2039 keV for ^{76}Ge)**



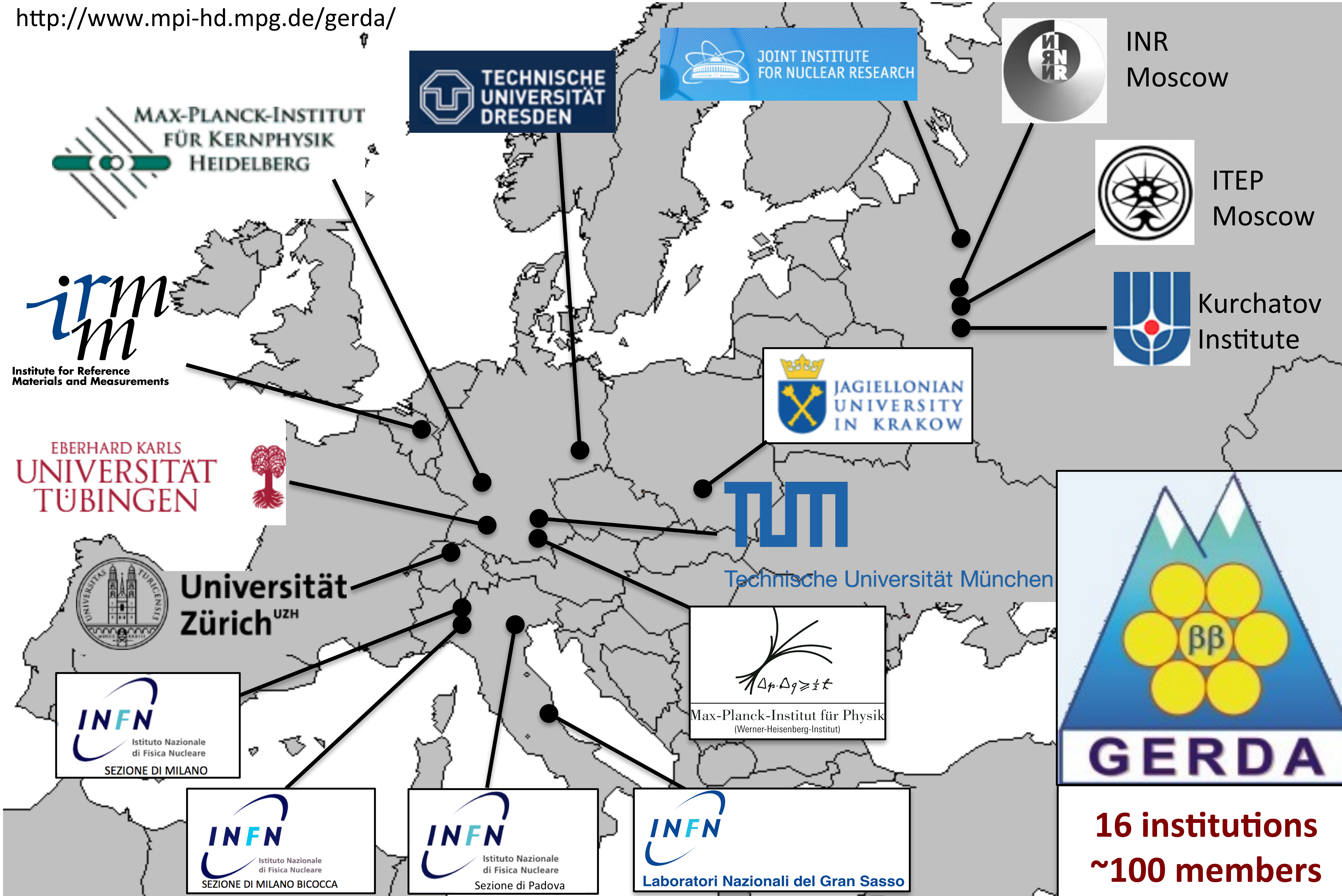
Experimental sensitivity



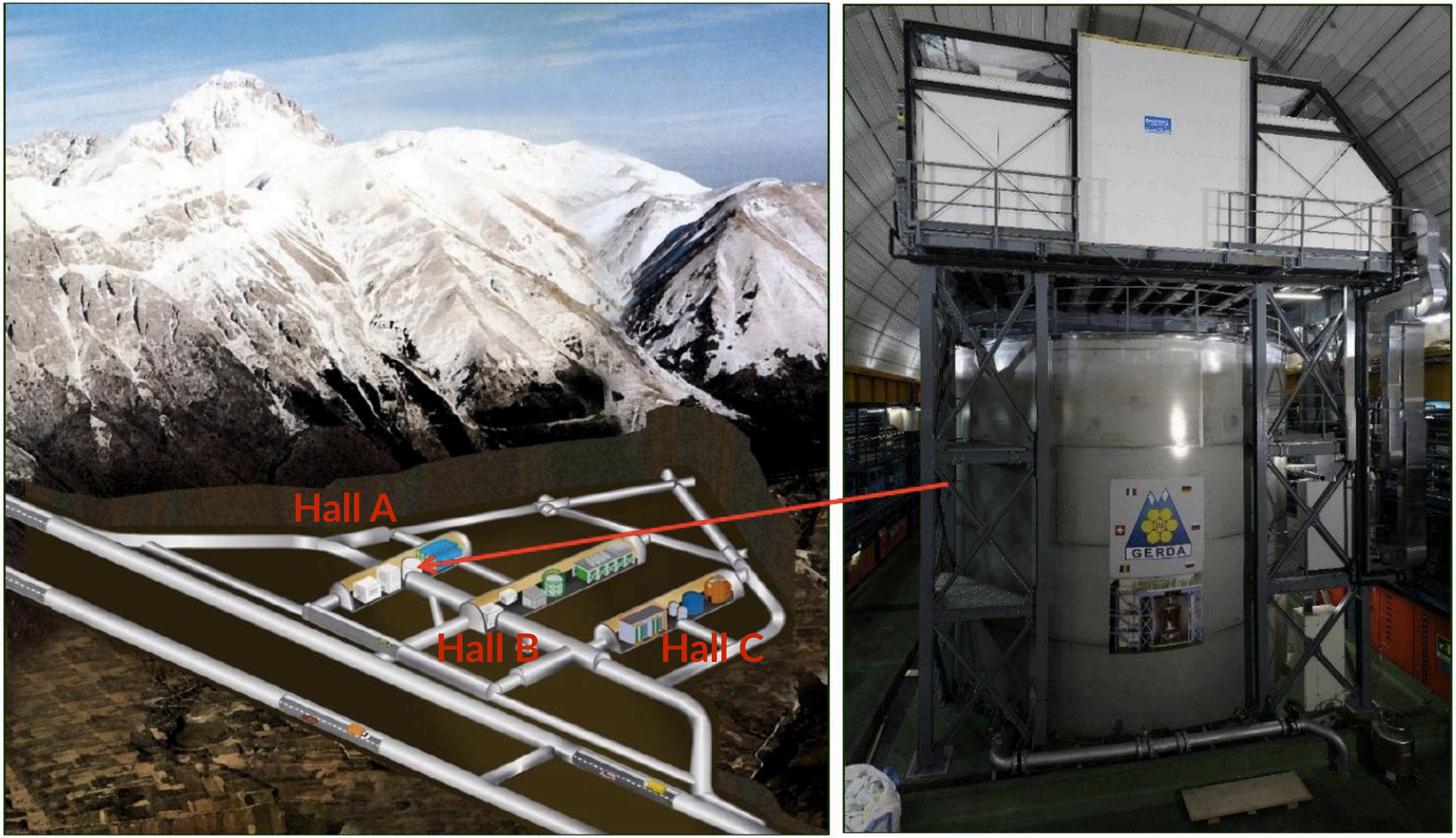
GERDA uses germanium detectors:

- enriched up to 86 % in the ^{76}Ge, ββ emitter (Natural I.A. 8 %)
- source = detector which implies high signal efficiency
- HPGe detectors with excellent energy resolution

The GERDA Collaboration

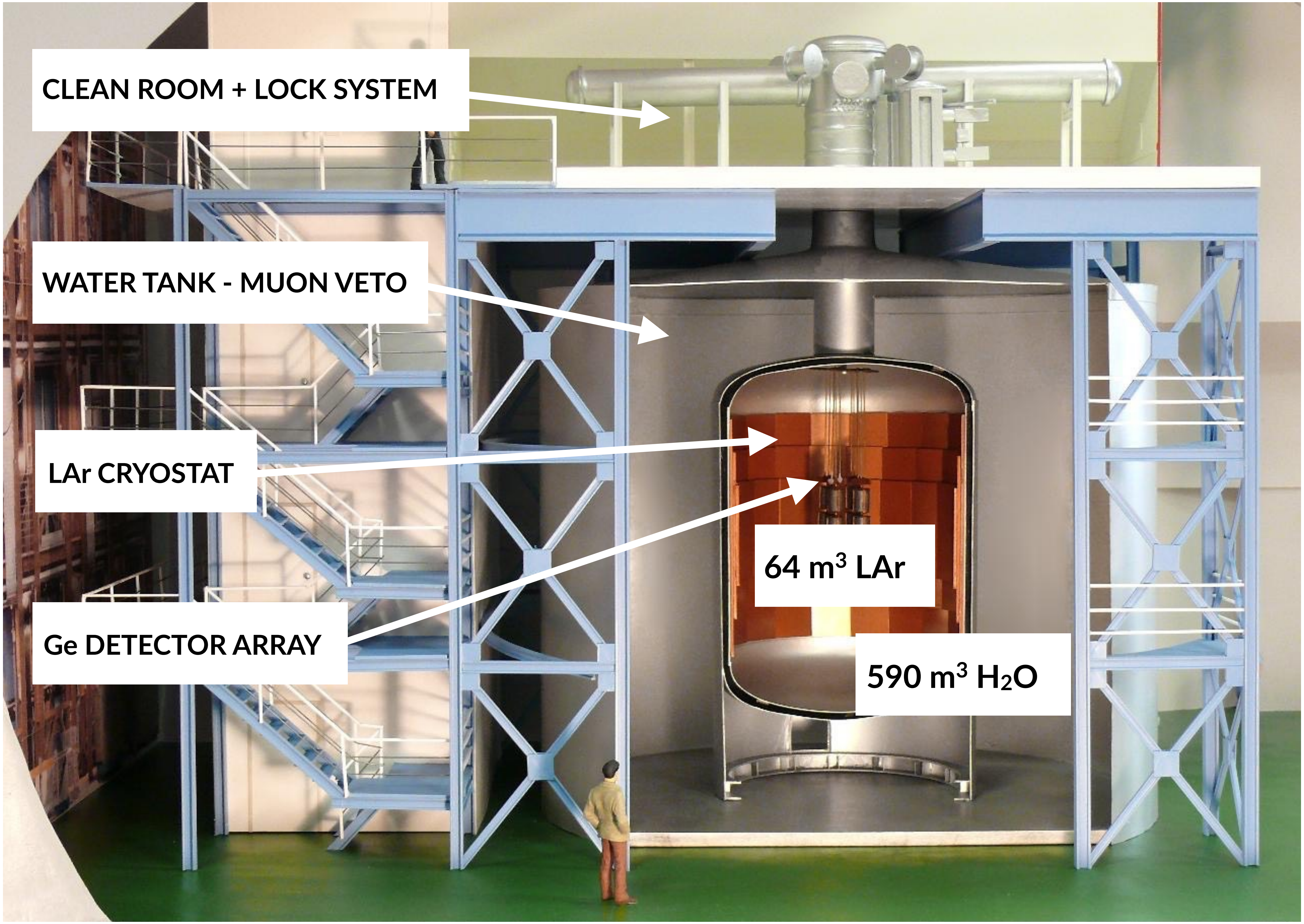


Location: INFN, Laboratori Nazionali del Gran Sasso



Shielded by 1500 m of rock, i.e. 3500 m.w.e

GERDA Experiment



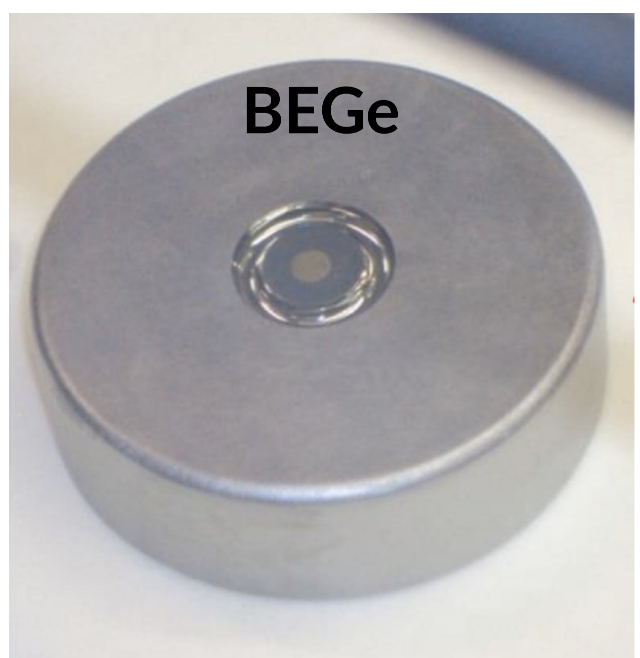
GERDA Phase I: detectors

COAXIAL DETECTORS

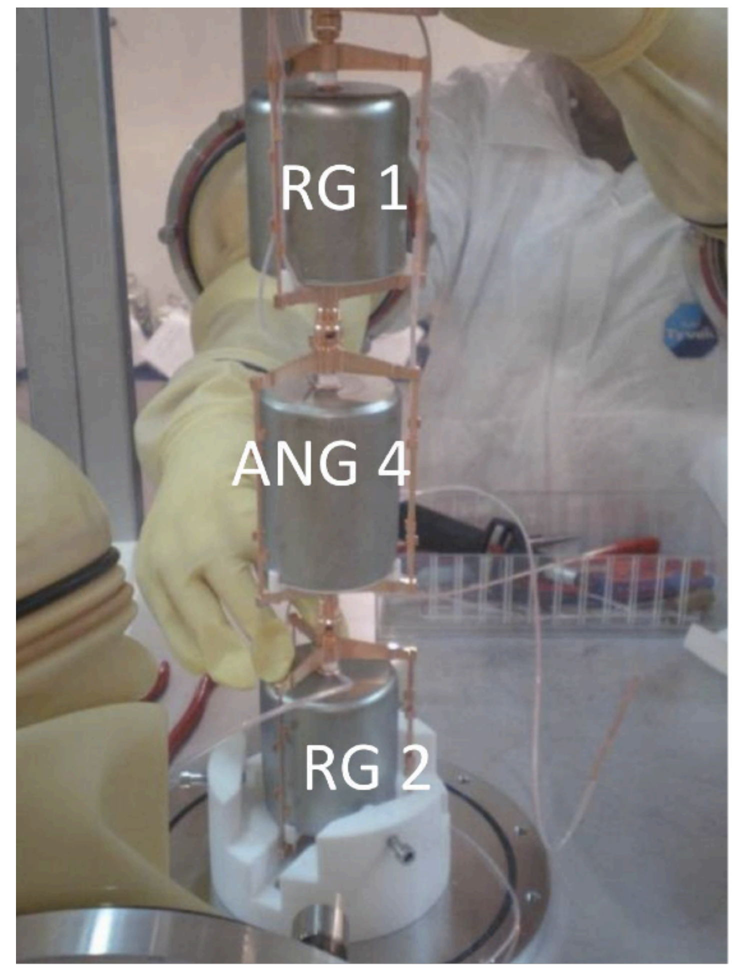
- from previous experiments (HdM, IGEX)
- total mass 17.7 kg
- average FWHM of 4.3 keV at $Q_{\beta\beta}$

Phase II BEGe DETECTORS

- better PSD and FWHM
- 5 BEGes used since July 2012
- average FWHM of 2.8 keV at $Q_{\beta\beta}$



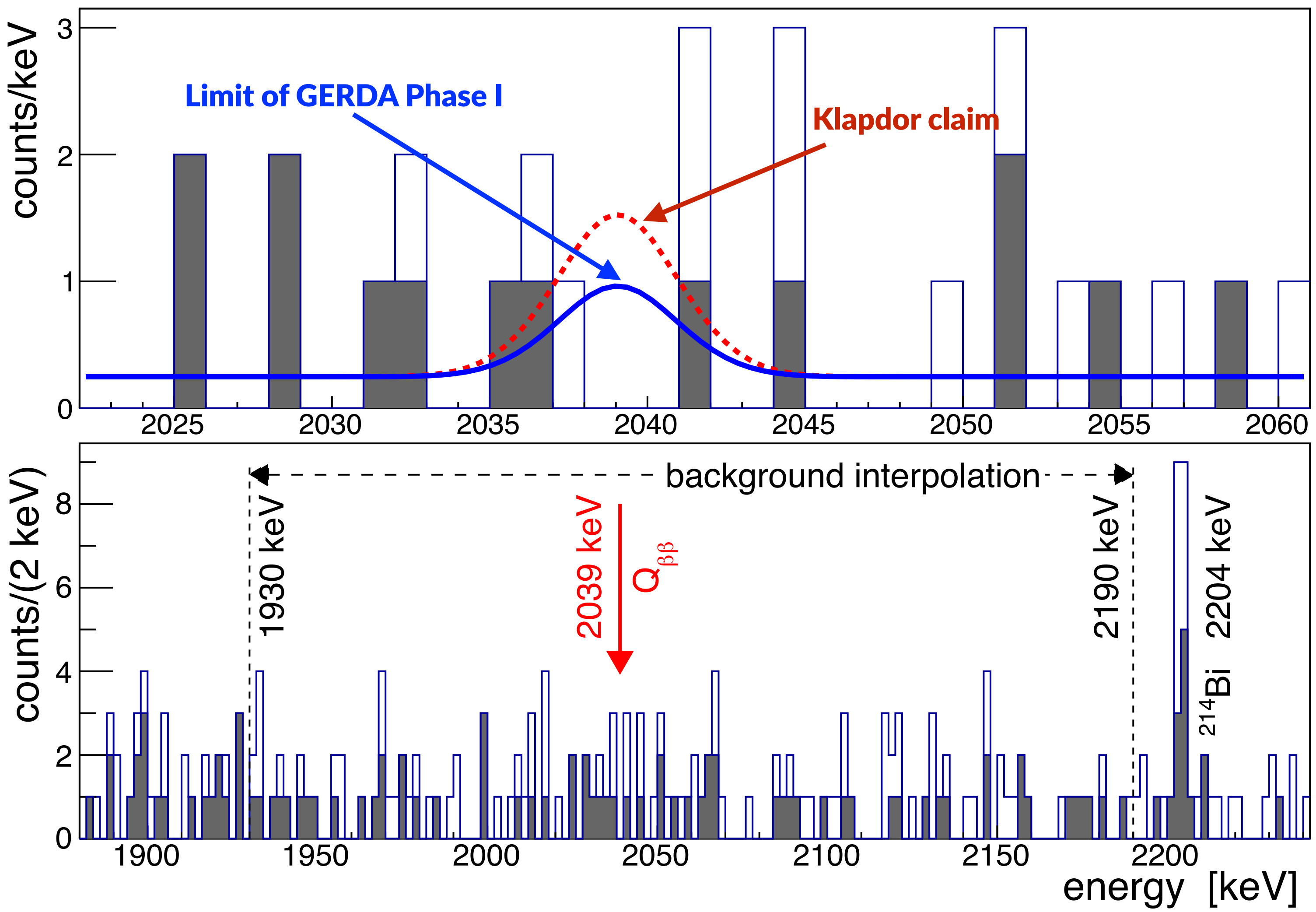
Coaxial STRING



BEGe STRING

GERDA Phase I: results

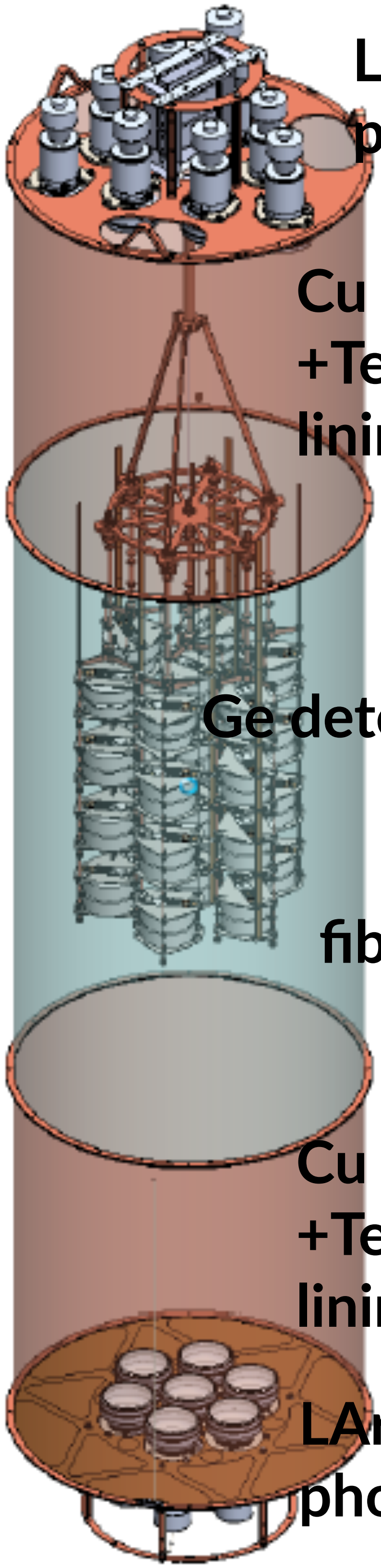
- from Nov 2011 to May 2013: exposure = 21.6 kg·yr
- **BI = (11±2) 10^{-3} cts/(keV kg yr)**
- Profile likelihood method: best N_ν= 0
  - new limit on the 0νββ: **$T^{0\nu}_{1/2}$ > 2.1·10^{25} yr 90% C.L**
  - median sensitivity **2.4 10^{25} yr**
- previous claim [Nucl. Instr. Meth. A 481, 149 (2002)] strongly disfavoured
- upper limit on neutrino mass **0.2 - 0.4 eV** (depending on N.M.E.)



GERDA Phase II upgrades

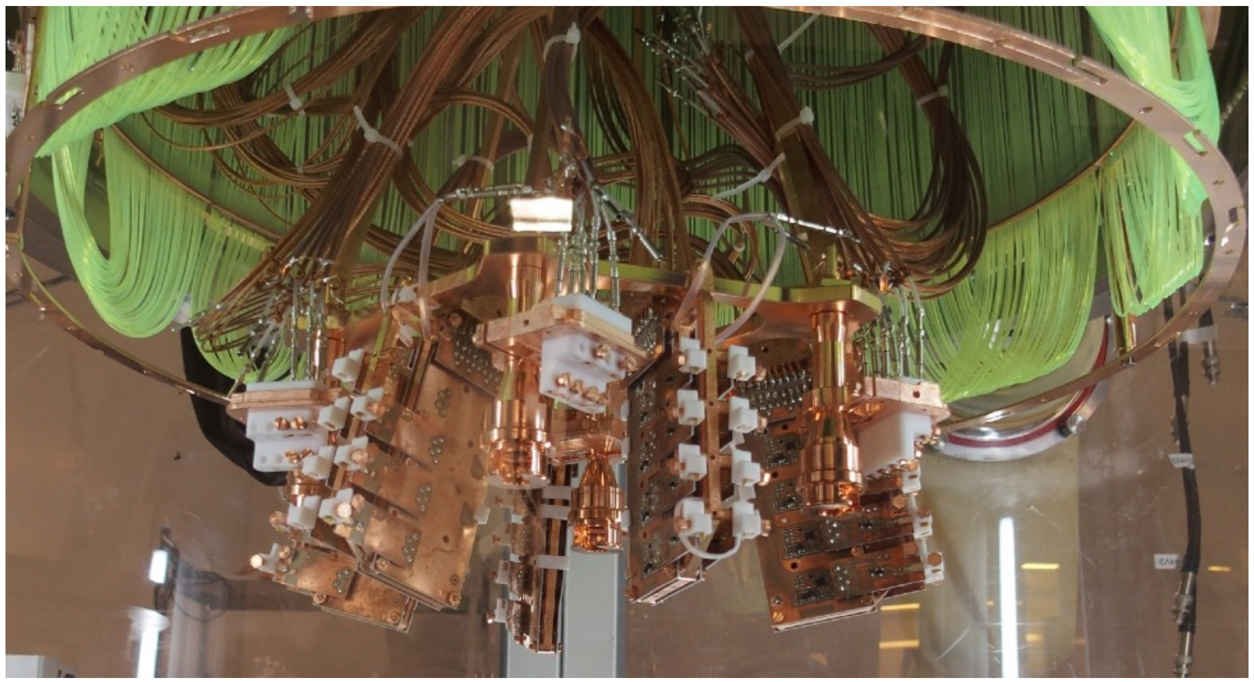
IMPROVEMENT W.R.T PHASE I

- 30 new BEGe detectors custom produced
- collect an exposure of ~100 kg·yr
  - more active mass (35.8 kg of ^{enr}Ge)
  - longer data acquisition (~ 3 - 4 yr)
- background reduction to ~10^{-3} cts/(keVkgyr)
  - new low mass holder, detector contacts and Front End (FE) circuits
  - pulse shape discrimination with BEGes
  - Liquid Argon (LAr) readout to veto residual external background



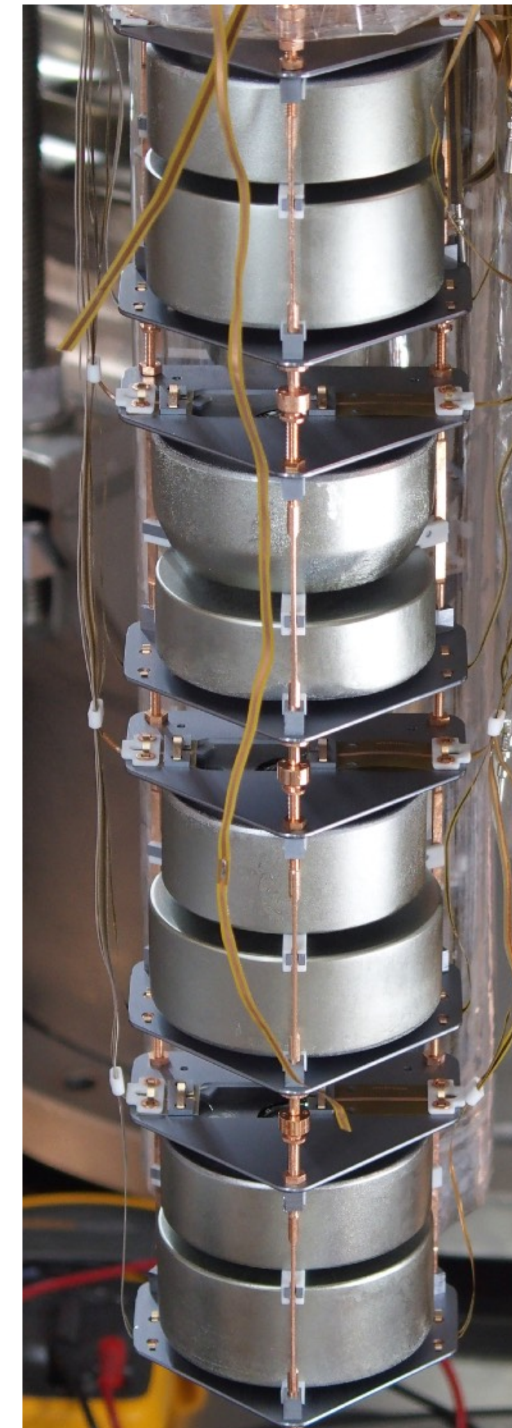
GERDA Phase II: Ge array

FE Circuit: new custom design, improved radio purity, 75 (35) cm above bottom (top) detectors



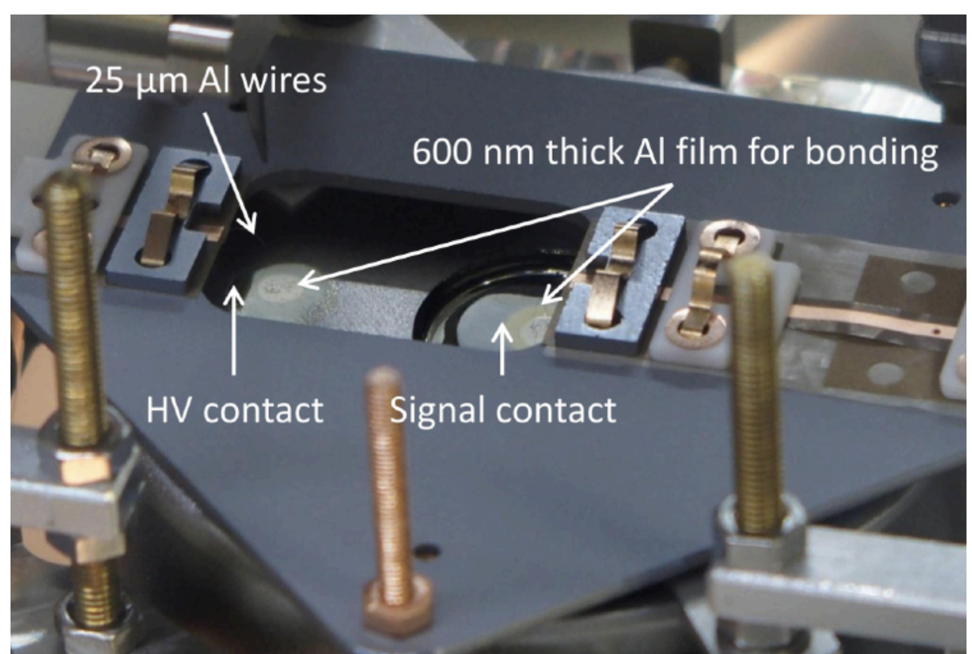
Holders: Si plates replace most of Cu parts (improved radiopurity)

Ge-string Mini Shroud (MS): nylon MS



HV and signal contacts: bonding wire replace spring loaded contact

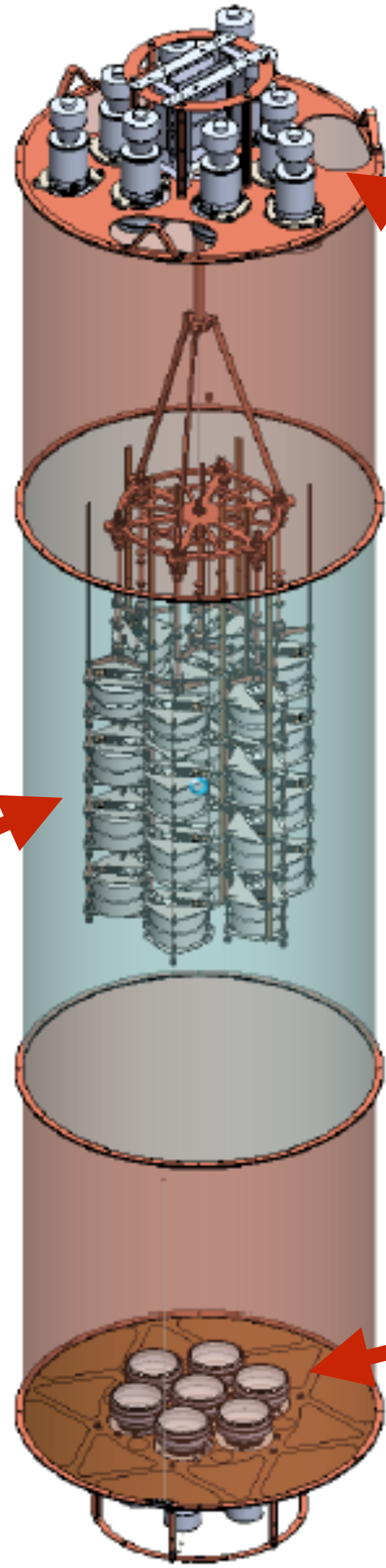
FE cables: custom low mass + low activity (Pyralux + Cuflon)



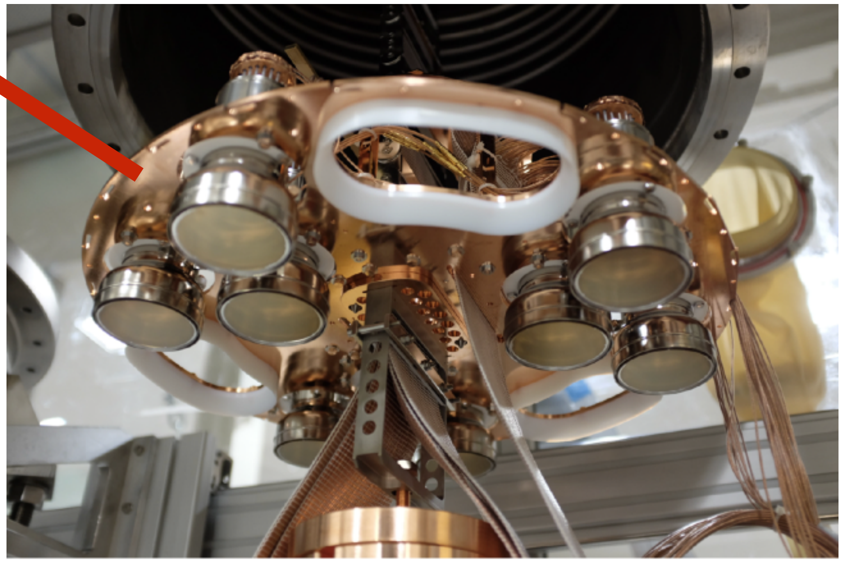
GERDA Phase II: Liquid Argon Veto

Integrated and commissioned since May 2015

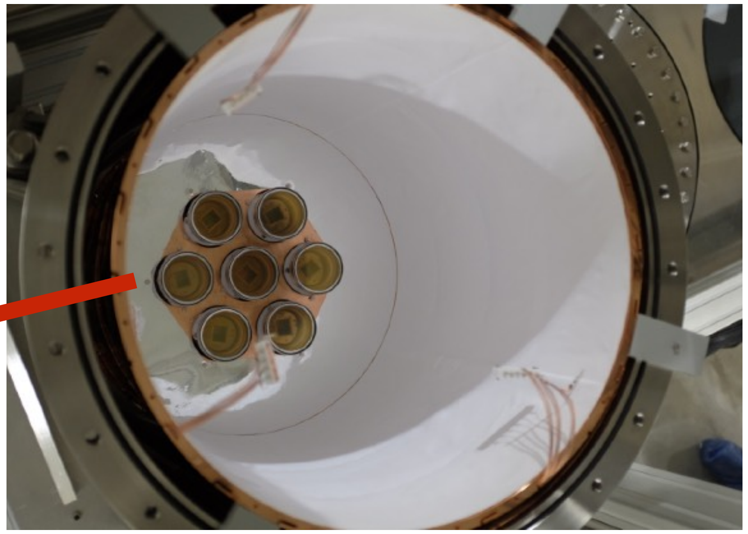
810 scintillating fibers coupled to 90 3x3 mm SiPMs (15 readout channels)



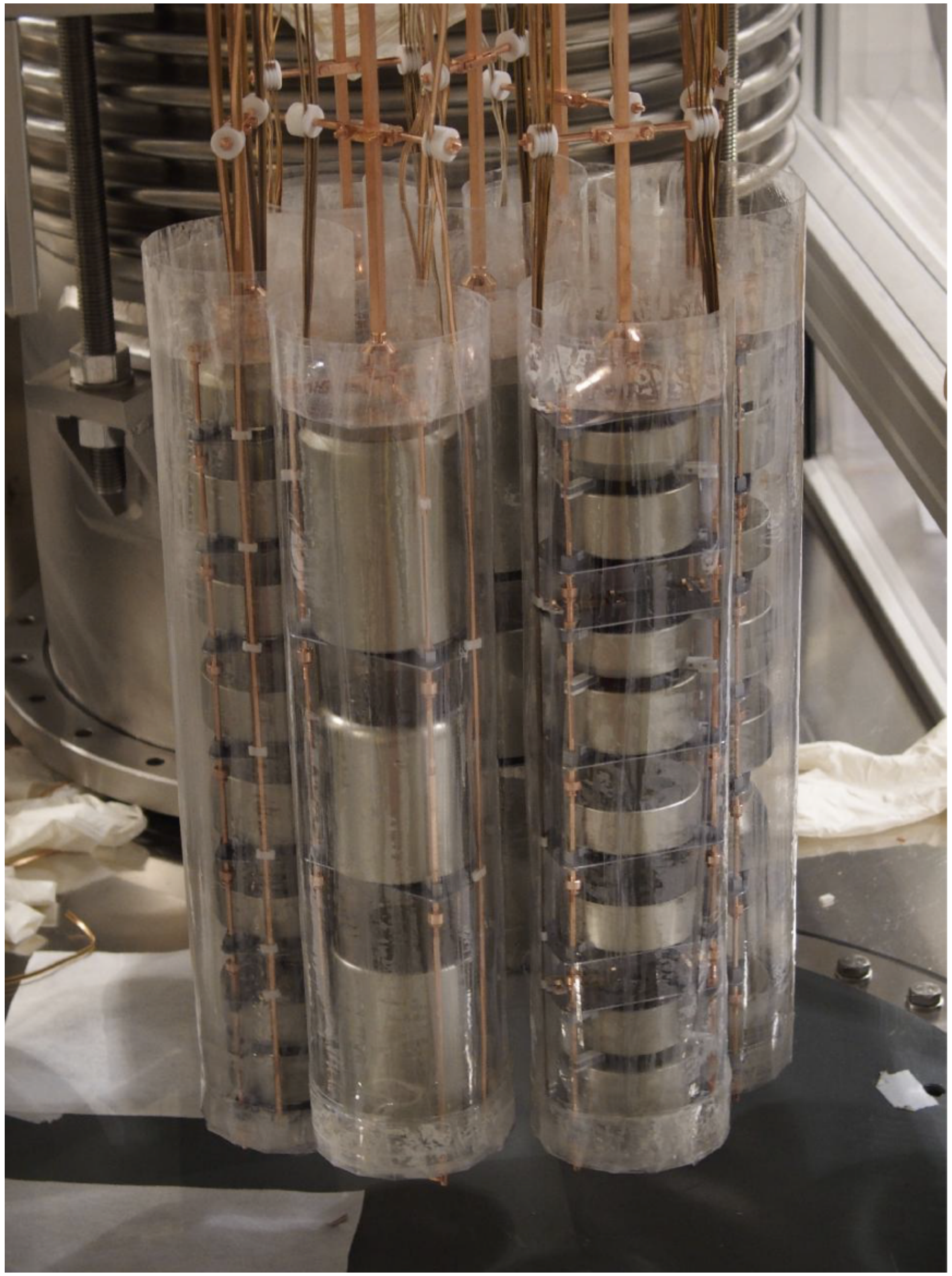
16 photomultiplier (PMTs)
9 TOP - 7 BOTTOM



Cu cylinder covered with wavelength shifting reflector foil



GERDA Phase II: Final Configuration



- final Phase II configuration with 7 strings installed
- strings surrounded by a nylon shroud to prevent ^{42}K from reaching Ge detectors

GERDA Phase II: Final Configuration

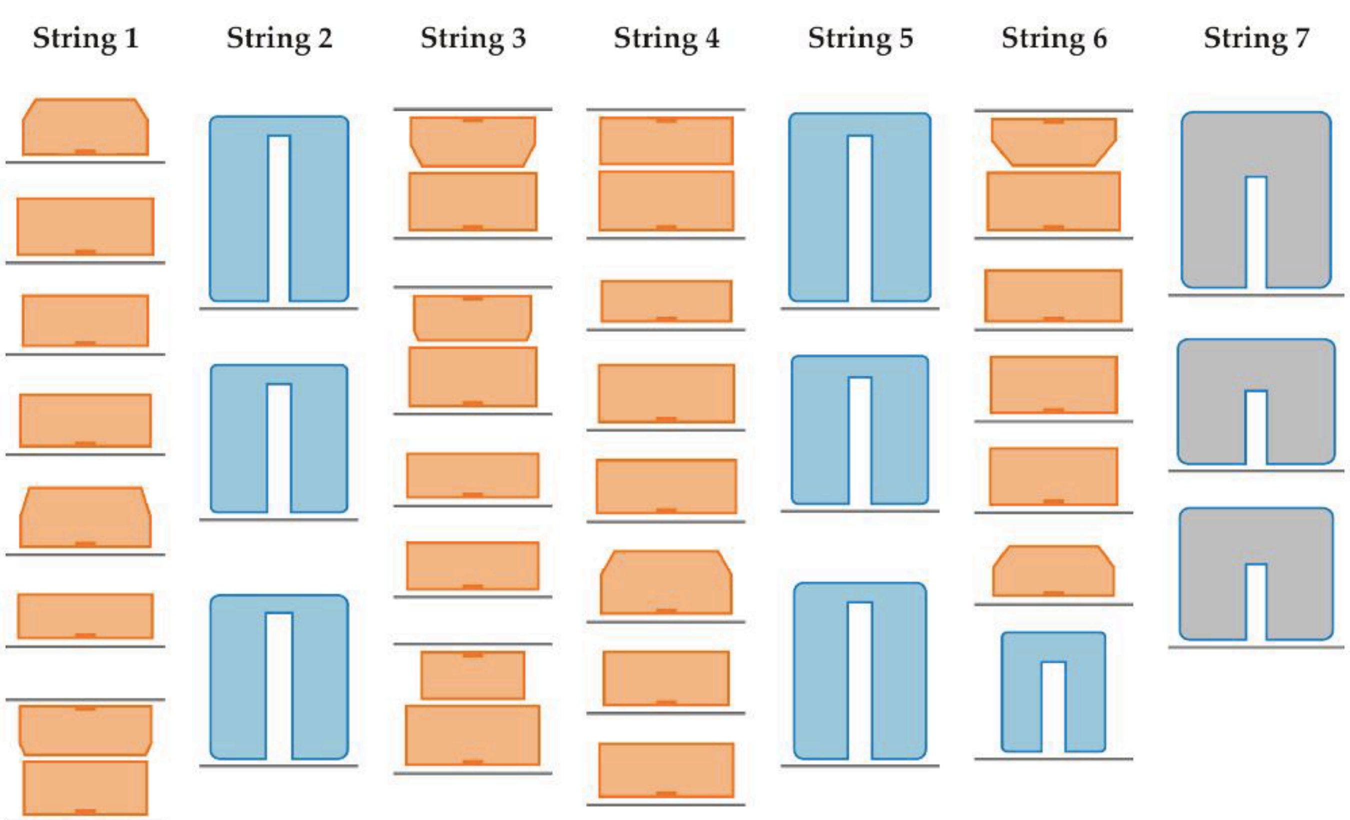
40 detectors arranged in 7 strings:

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

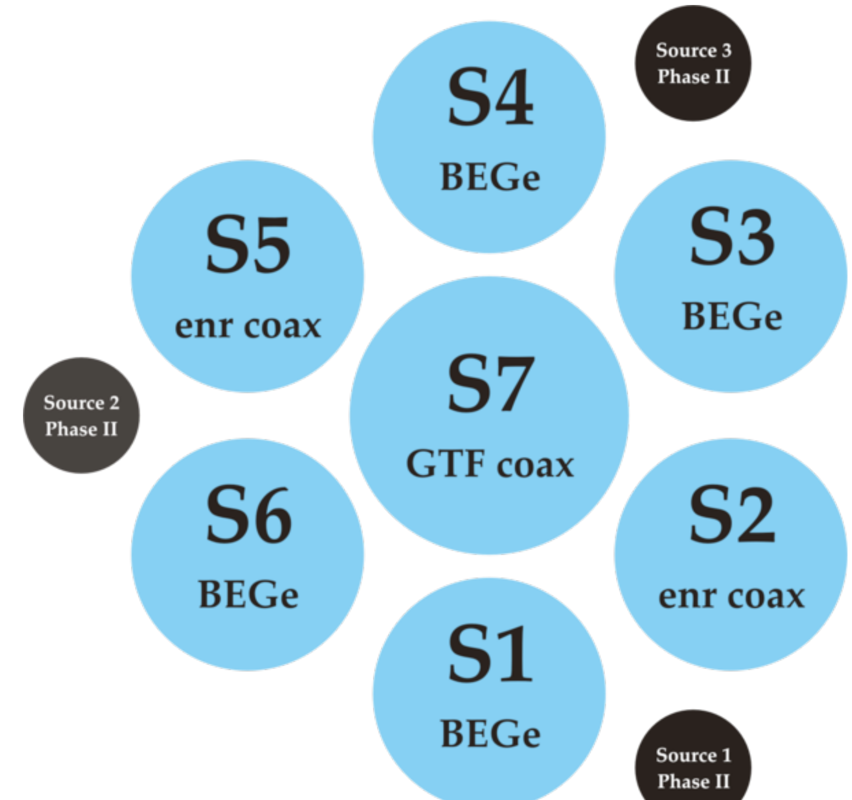
35.8 kg of ^{enr}Ge

First Phase II data release:

- 131 live days:
  - 25/12/2015 - 01/06/2016
- 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



unwound lateral view of detectors array



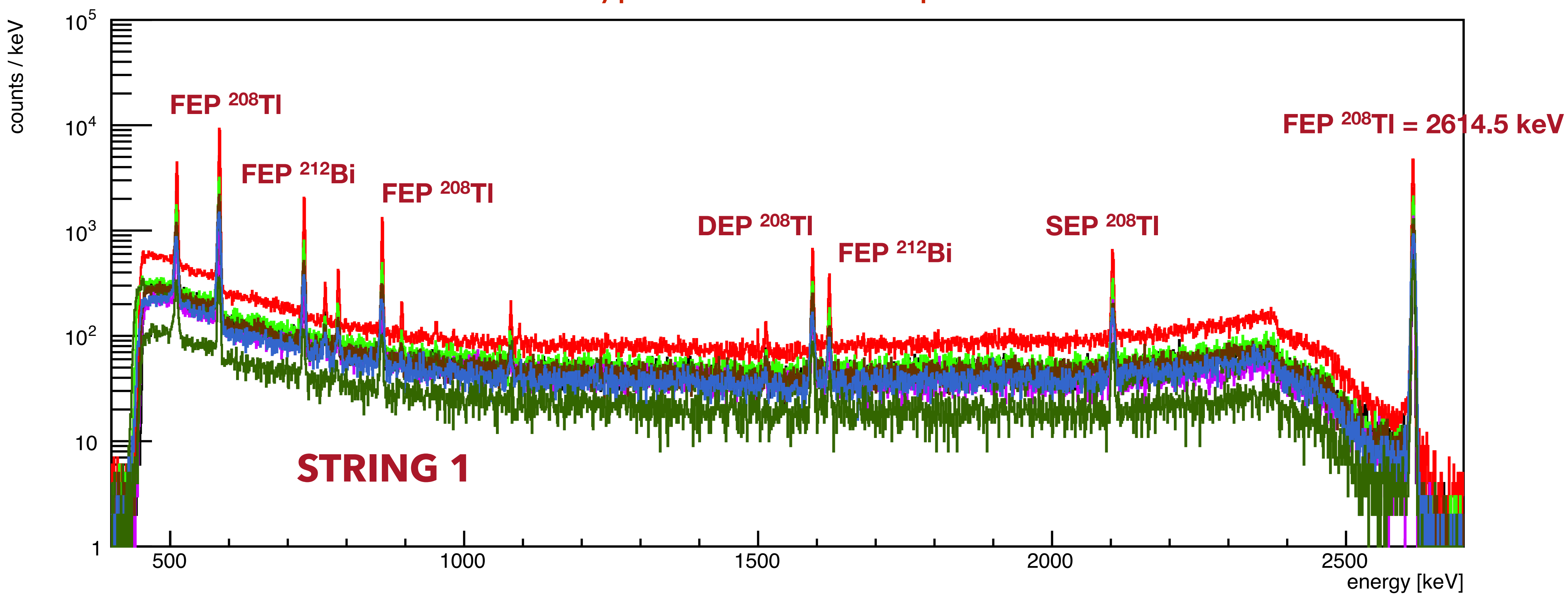
top view of detectors array

Energy Scale and Resolution

Irradiations with ^{228}Th sources to determine the energy scale (each ~10 days)

- energy evaluated with an optimized cusp-like filter [EPJC 75 (2015) 255]

Typical Calibration Spectrum



Energy Scale and Resolution

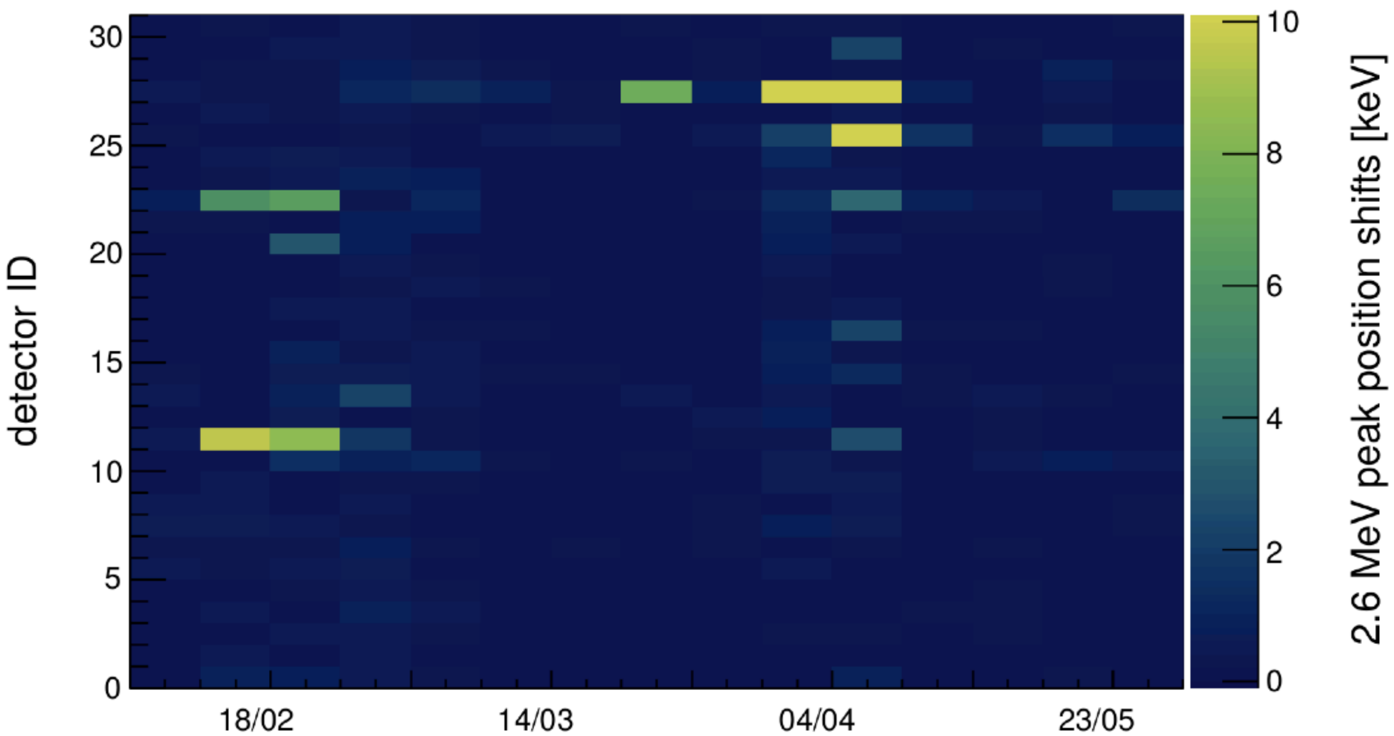
Irradiations with ^{228}**Th** sources to determine the energy scale (each ~10 days)

- energy evaluated with an optimized cusp-like filter [EPJC 75 (2015) 255]
- ≲ **1 keV** shift between calibrations
- data are removed from 0νββ analysis if the energy scale is not properly evaluated

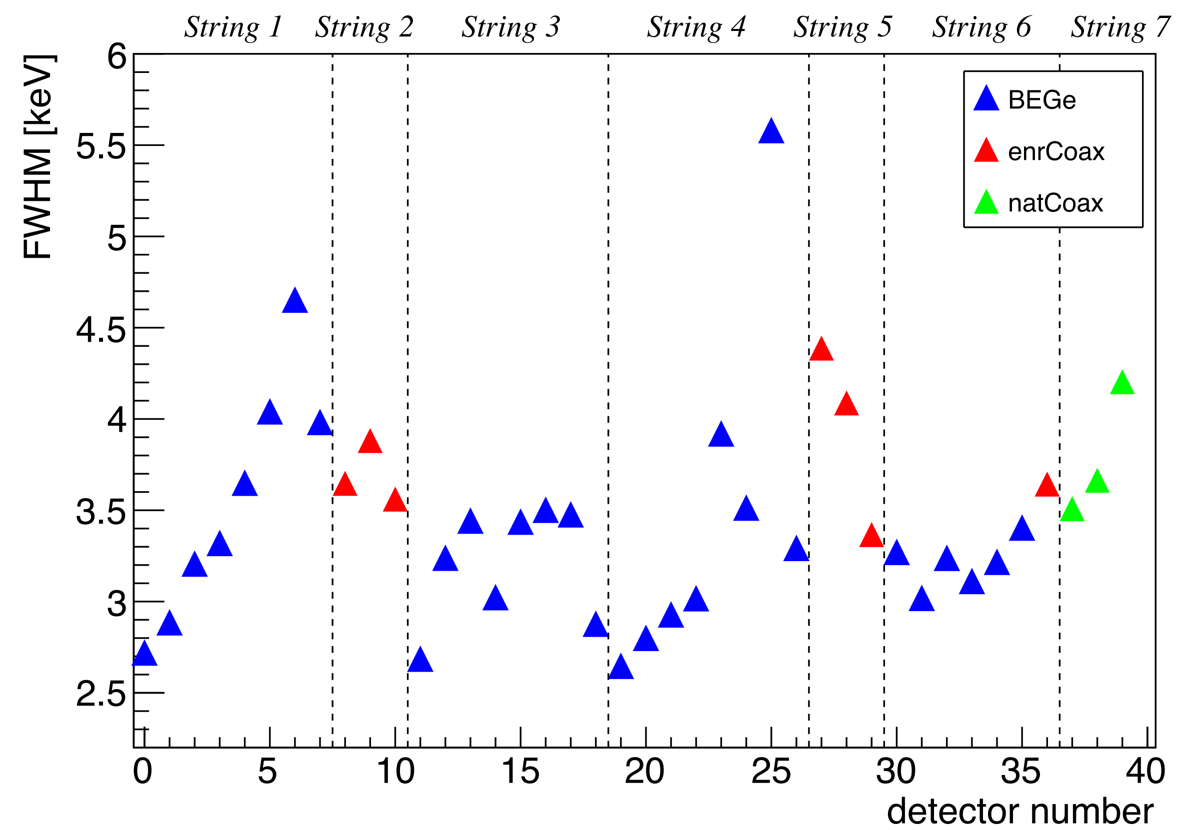
Performance on full physics data-set:

- **FWHM$_{coax}$ @ $Q_{\beta\beta}$= 4.0 ± 0.2 keV**
- **FWHM $_{BEGe}$ @ $Q_{\beta\beta}$= 3.0 ± 0.2 keV**

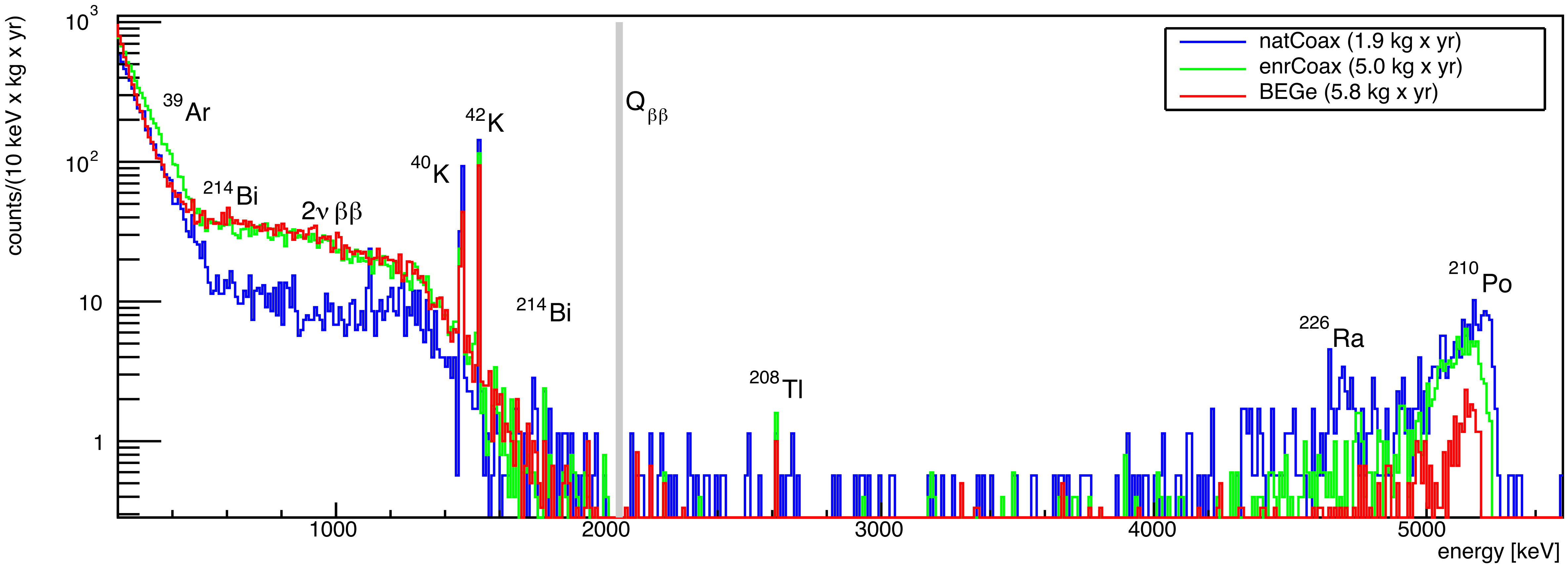
energy shift between calibration runs



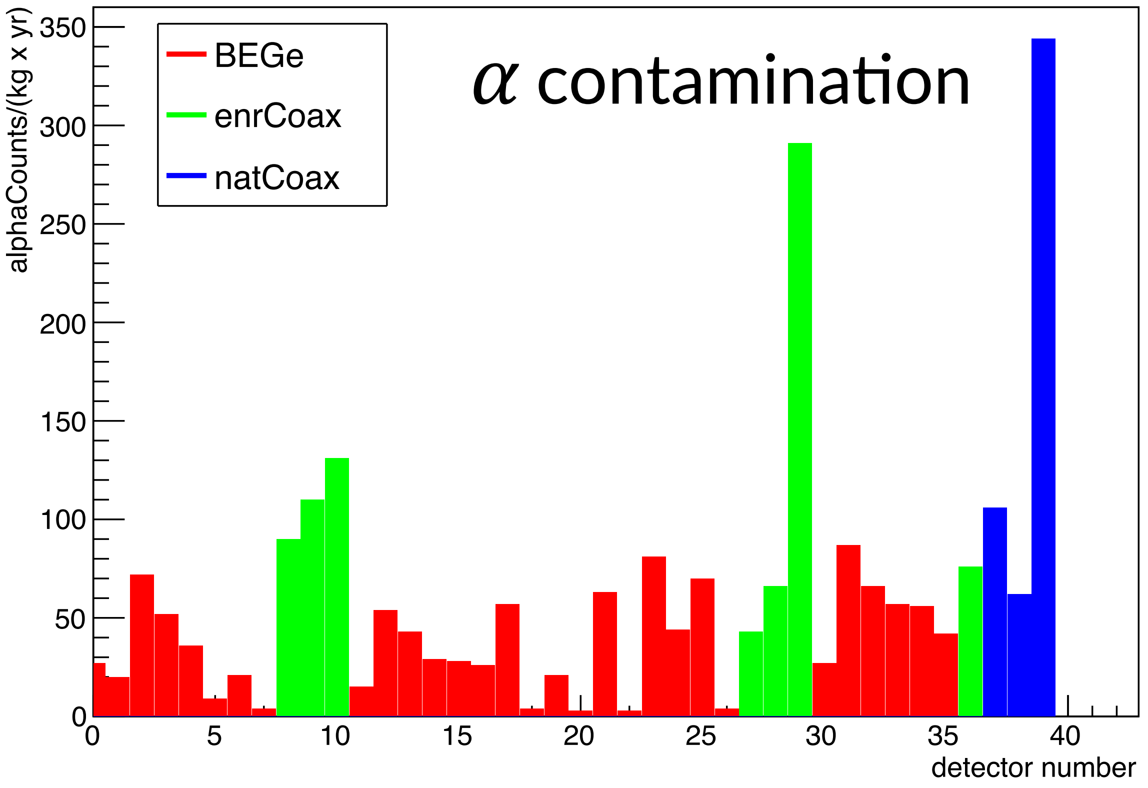
FWHM of 2614.5 keV peak



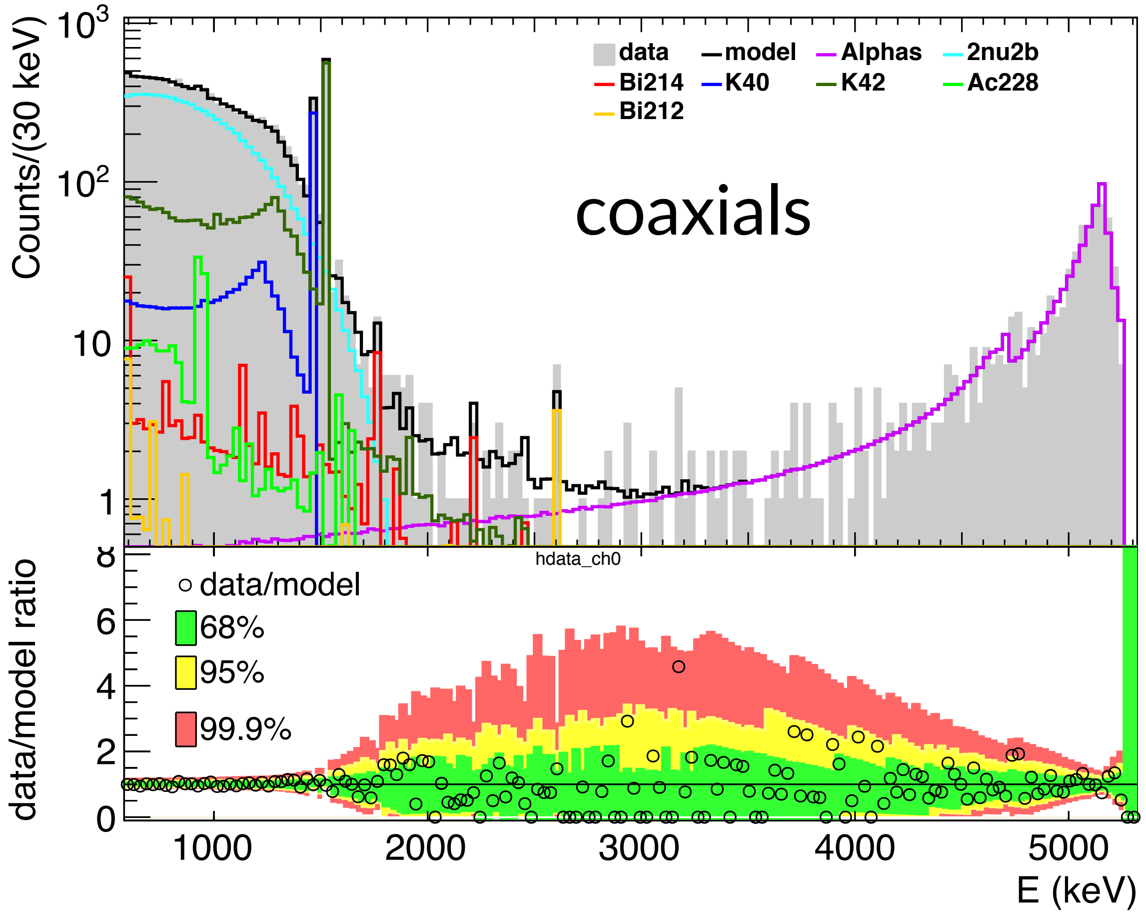
Background

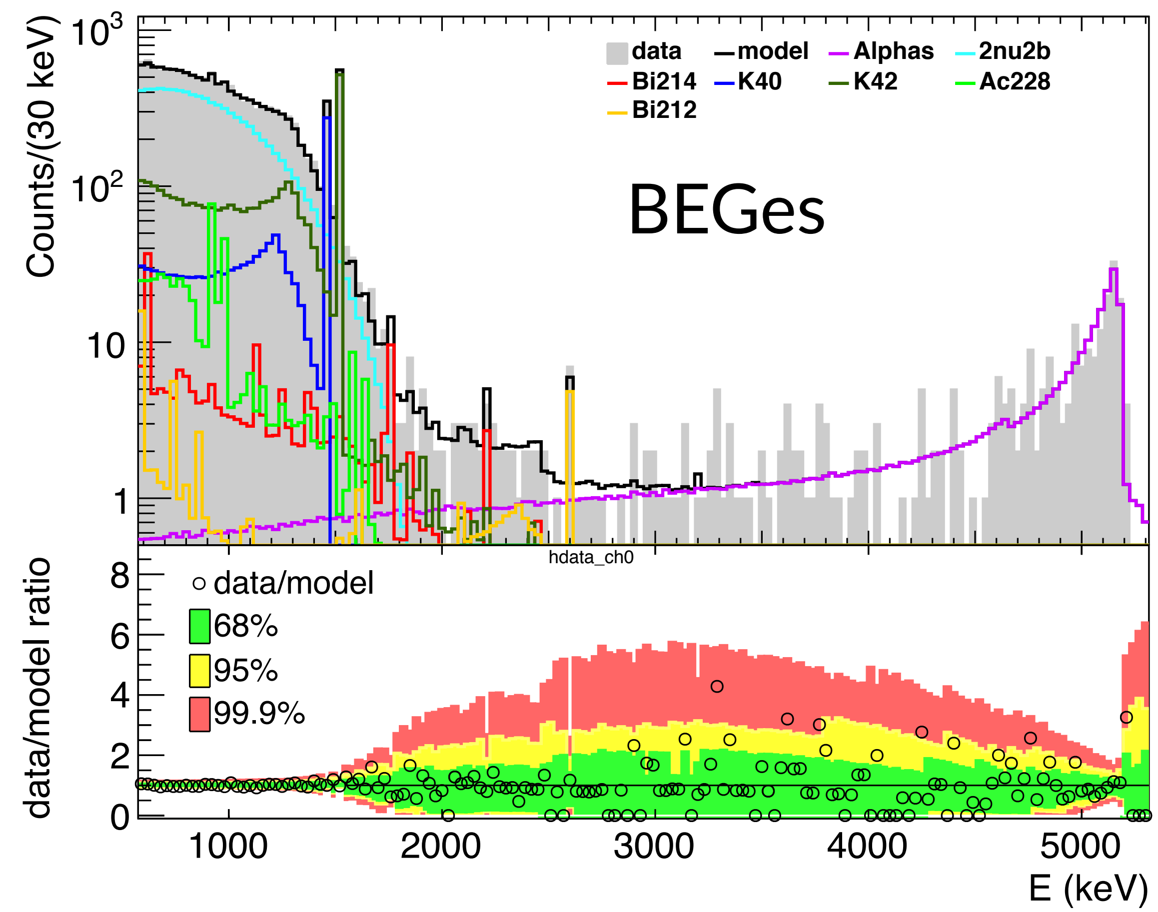


- same isotopes as in Phase I
- **Th/Ra** contributions sizable with screening measurements
- α contamination larger for Coax than for BEGe, observed to decay with half-life compatible with **^{210}Po + slowest component**



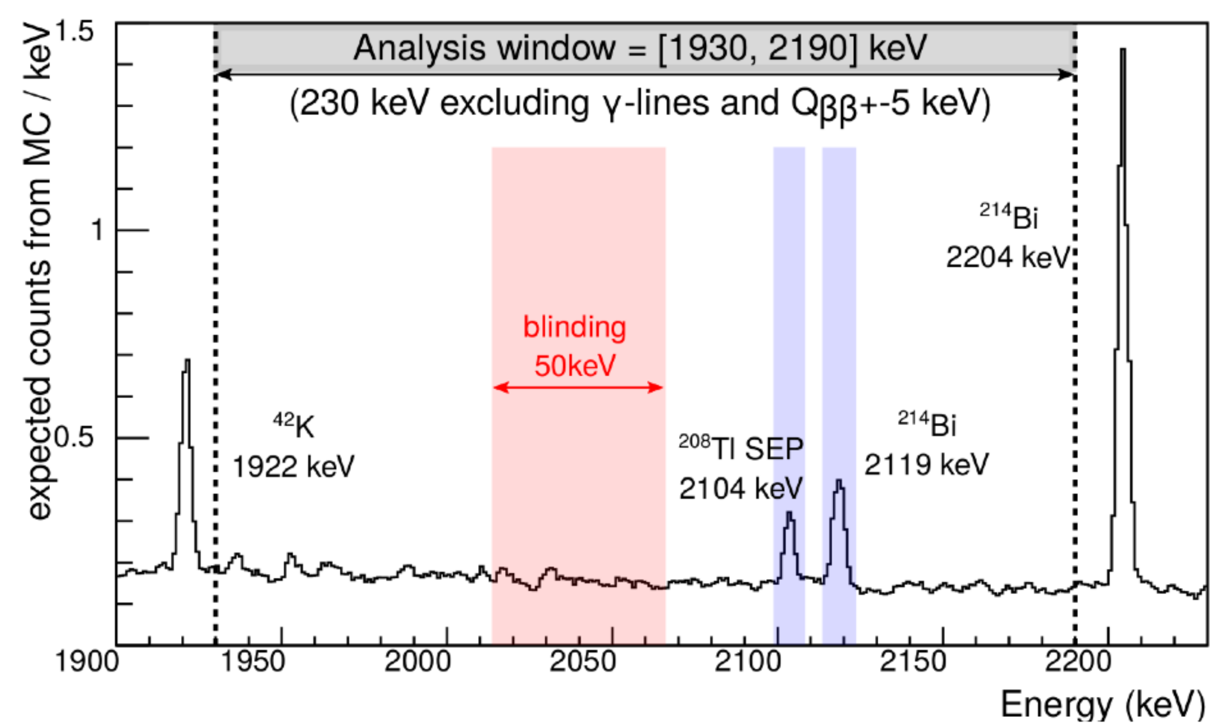
Background modeling





flat background expected in the ROI; main components:

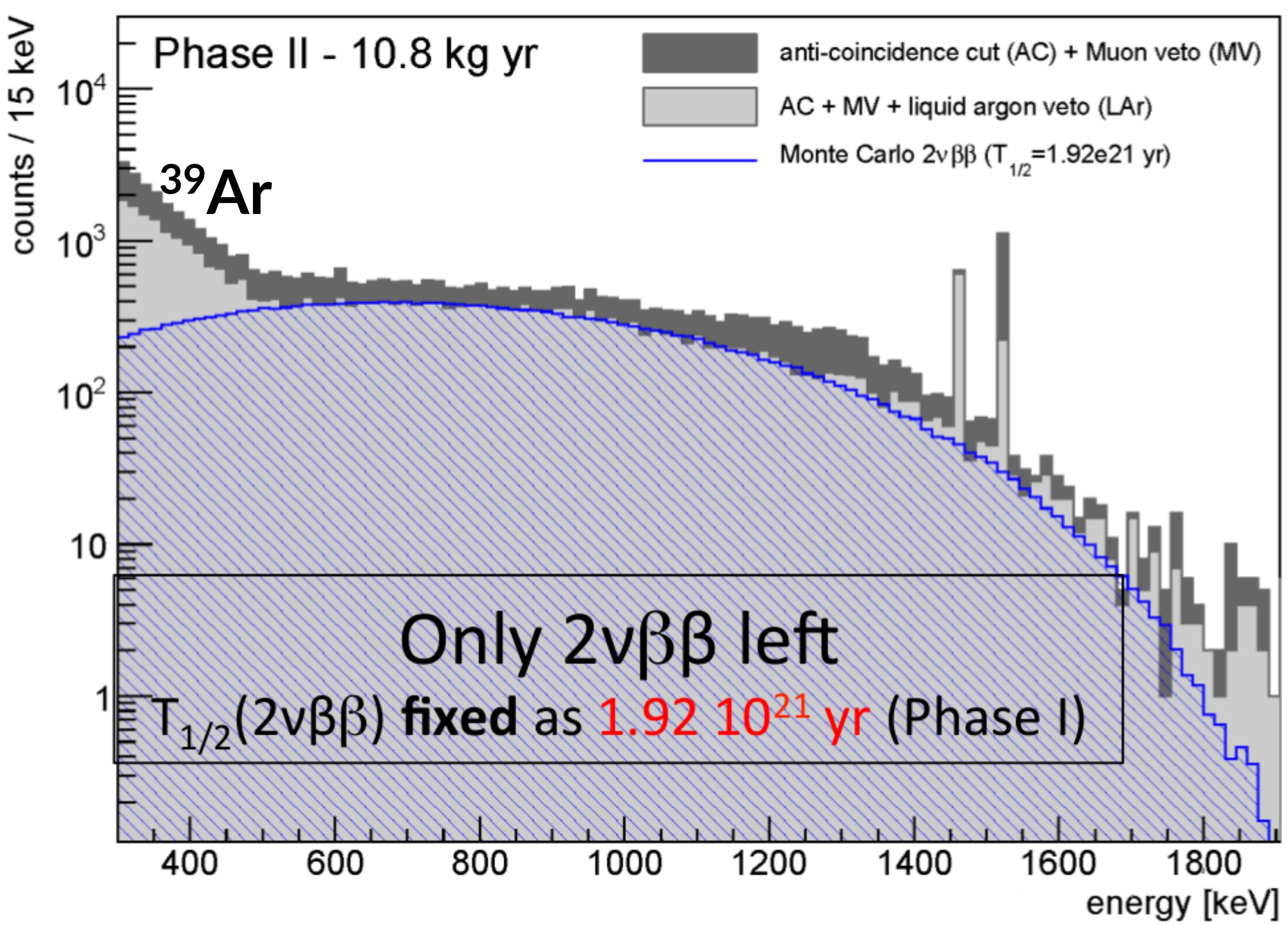
- α from ^{210}Po and ^{226}Ra
- β from ^{42}K
- γ from ^{208}Tl and ^{214}Bi

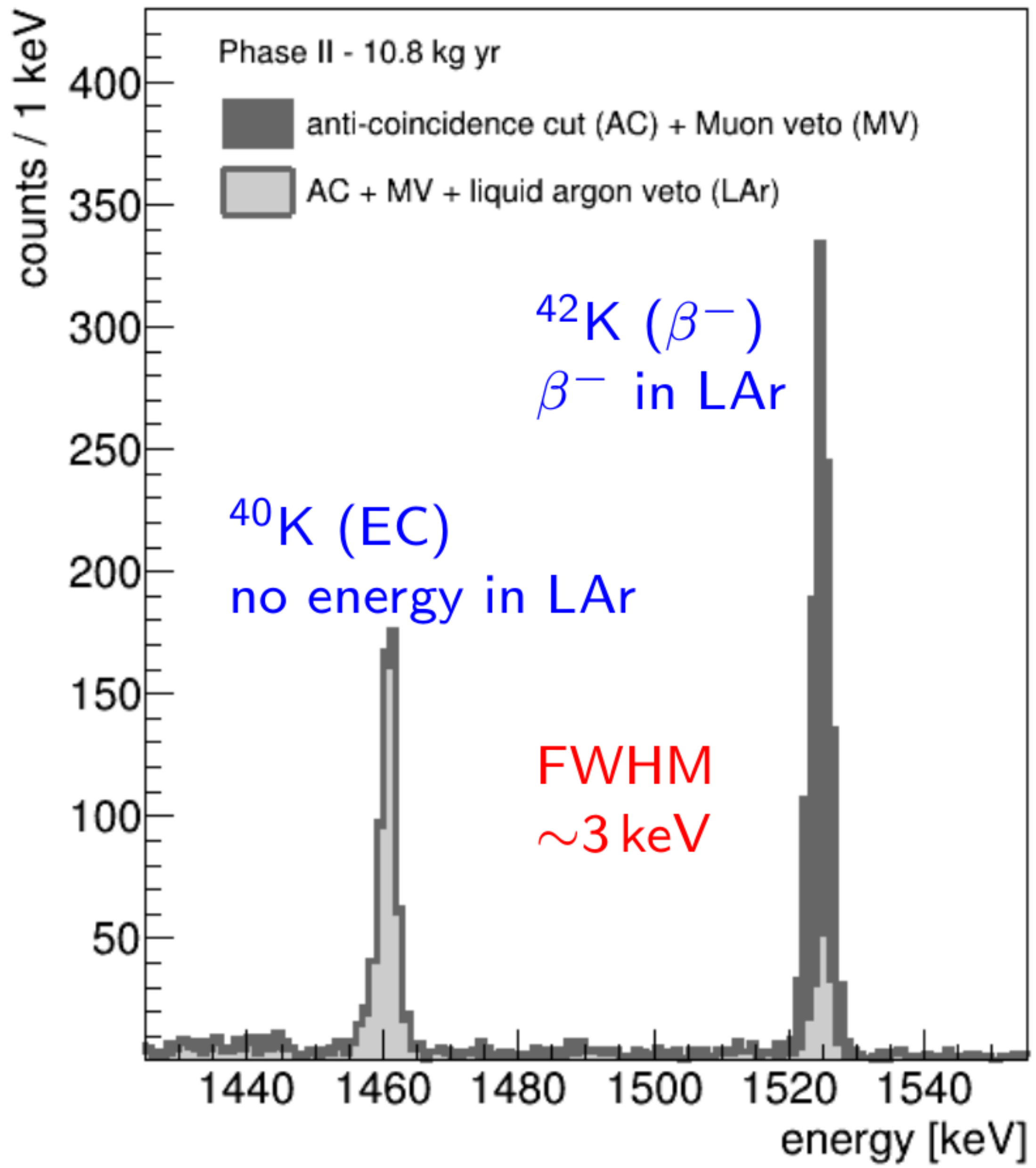


LAr veto background suppression

Detection of LAr scintillation light allows to veto background events

- **(70.4 ± 0.3)%** survival fraction in the range **0.6-1.3 MeV**
- **^{40}K/^{42}K** Compton continua completely suppressed



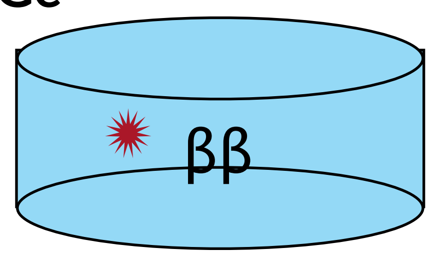


γ-rays survival fractions:

- ^{40}K (EC) = 100 %
- ^{42}K (β−) ~ 20 %

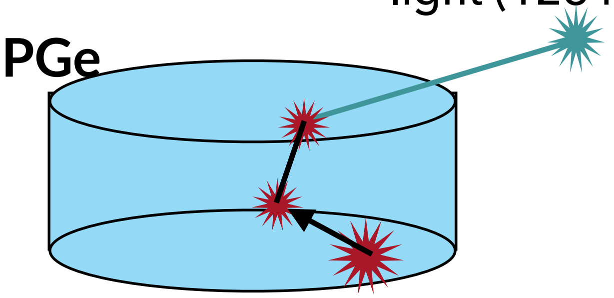
PSD for BEGe detectors

Signal

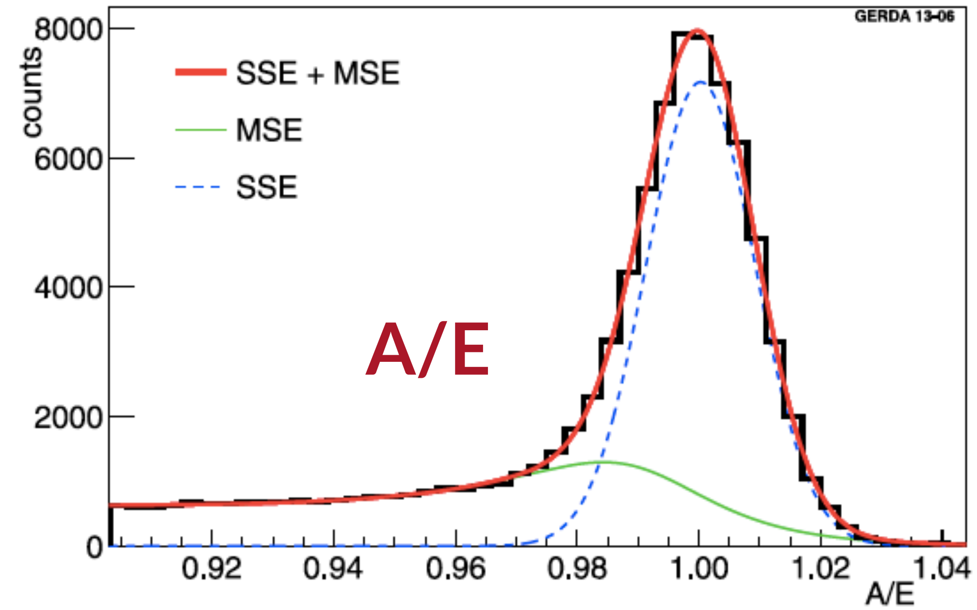


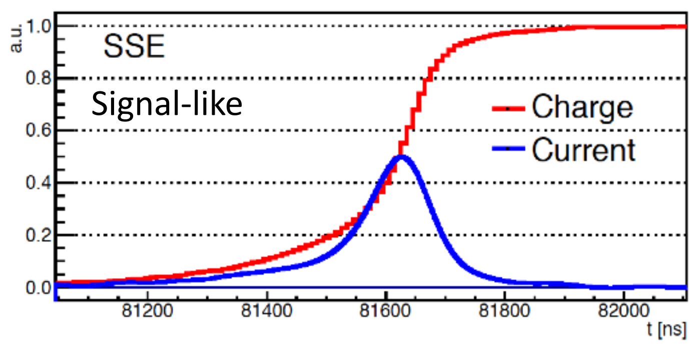
SINGLE SITE EVENT (SSE)

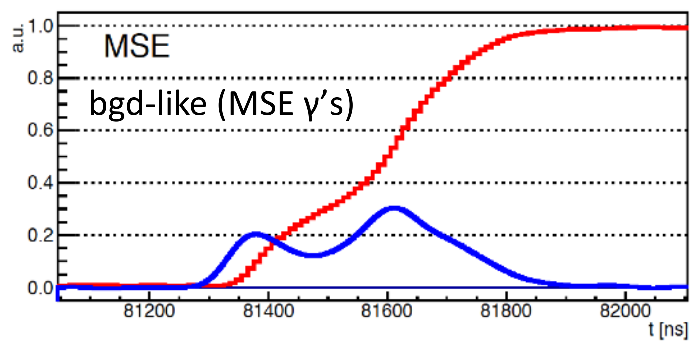
Background

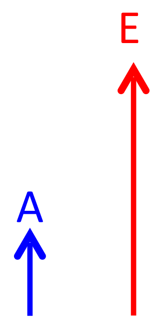


MULTI SITE EVENT (MSE)









Pulse shape parameter for BEGes is

$$A/E = \frac{\text{amplitude of Current pulse}}{\text{amplitude of Charge pulse}}$$

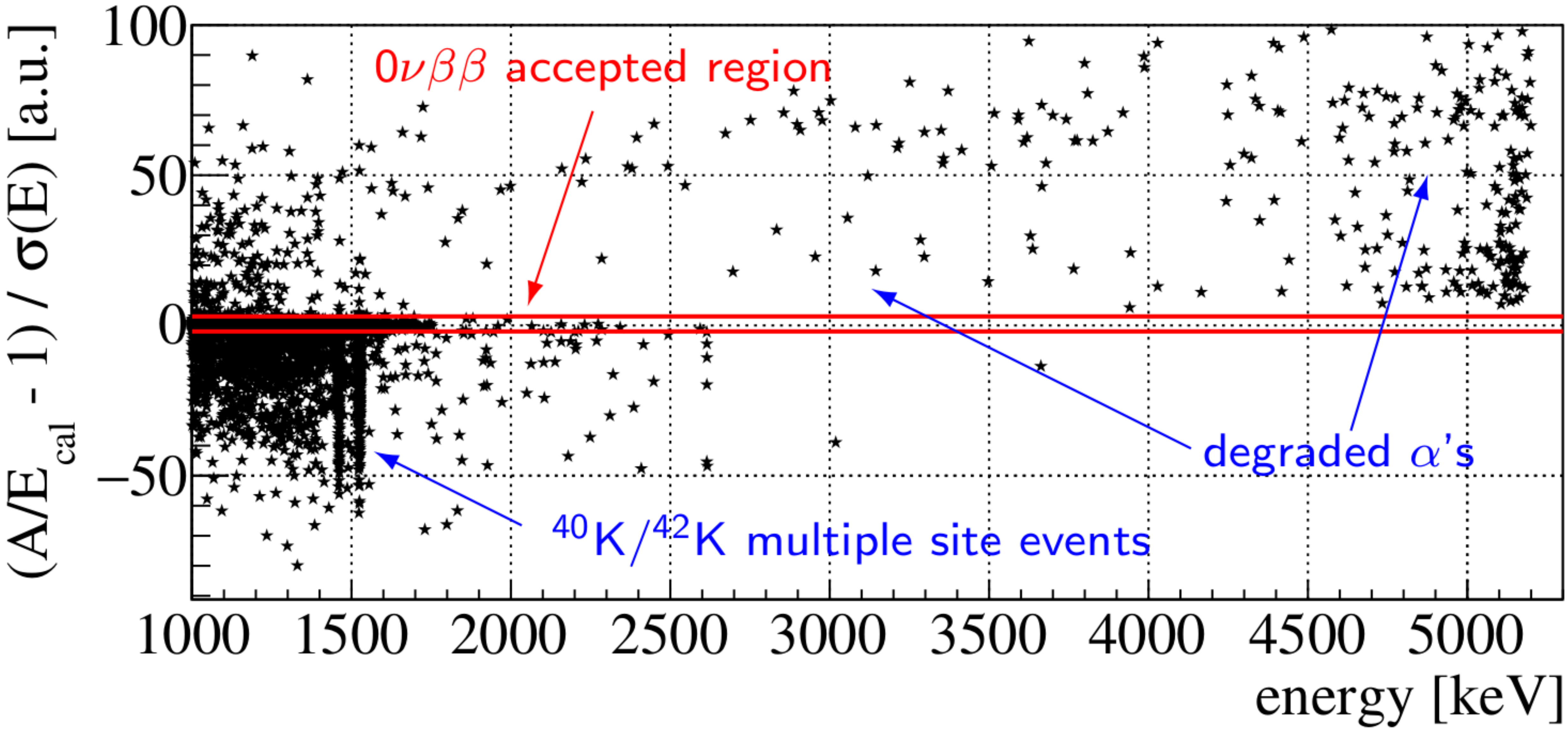
characteristic value for SSE events

Event-by-event selection:

high A/E : events on p+ electrode (e.g. α from ^{210}Po)

low A/E : events on n+ electrode, multiple scattering

PSD for BEGe detectors



0νββ acceptance from ^{228}Th calibrations (DEP):

ε_{PSD}(BEGe) = (87.3 ± 0.9)%

double check at low energy with 2νββ events

PSD for Coaxial detectors

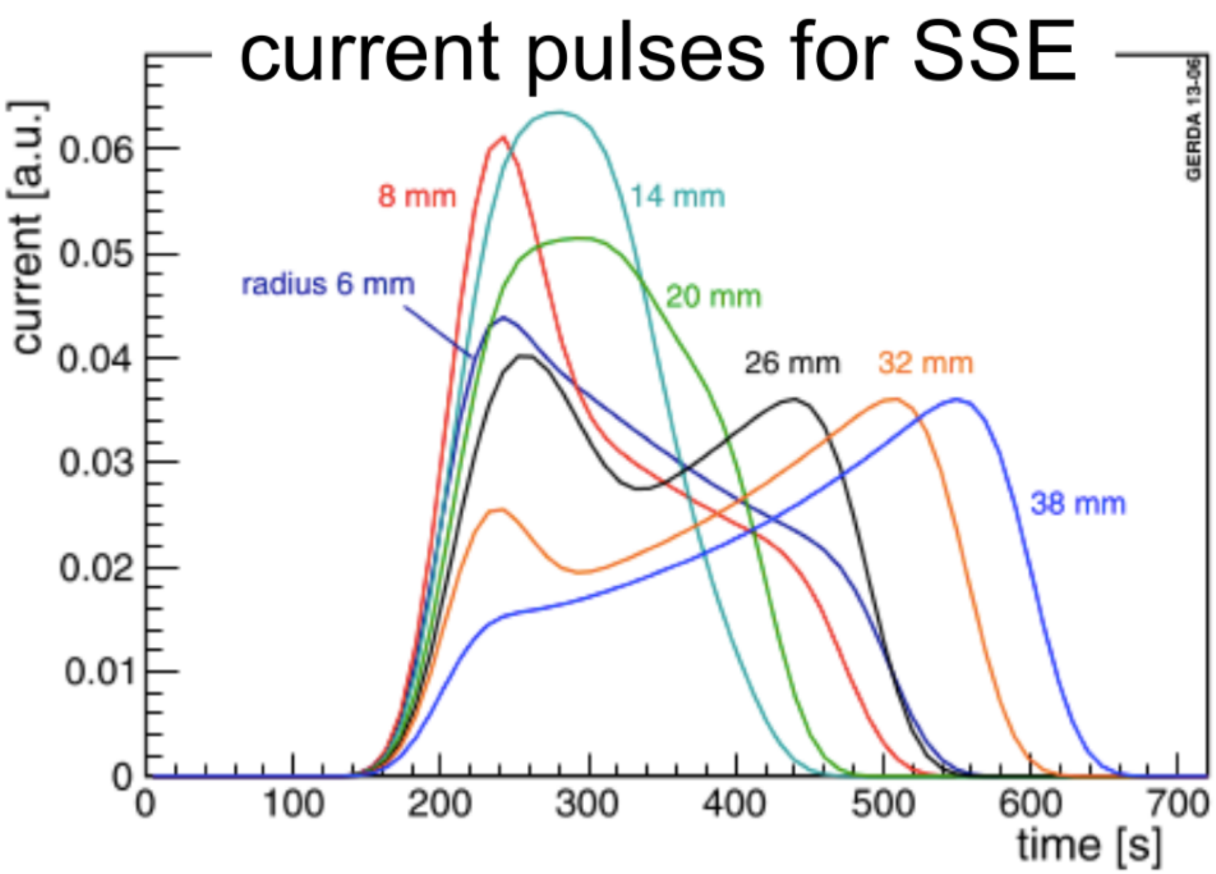
Multiple site event suppression **as in Phase I** *[EPJC 73 (2013) 10]*:

2 different Artificial Neural Network (ANN) method are used:

First one to discriminate **MSE** from **SSE** trained using calibration data:

- **signal (SSE)** DEP from ^{208}Tl at 1592 keV
- **background (MSE)** ^{212}Bi γ-line at 1620 keV

acceptance for 0νββ: **ε^{MSE}(coax) = (85 ± 5)%**



NEW ANN to suppress α-event at p+ contact

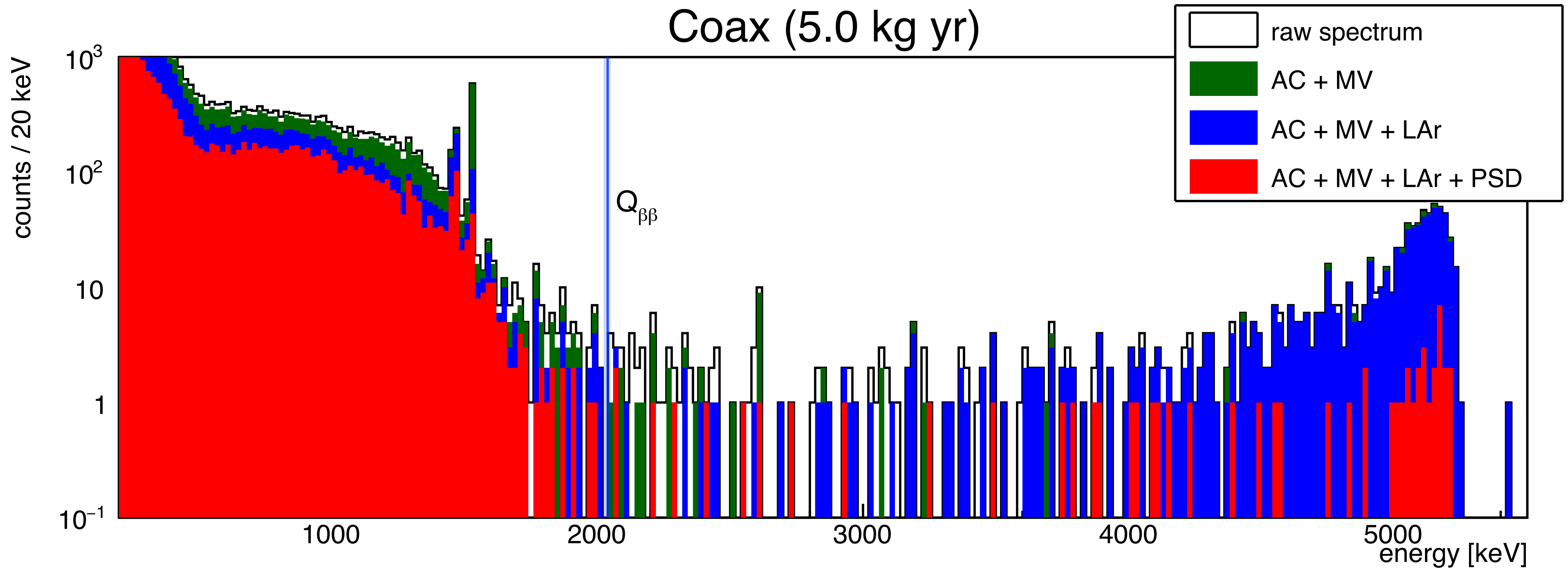
- test/train sample from data
- acceptance for 0νββ: **ε^{α}(coax) = (93 ± 1)%**

Combined 0νββ acceptance:
ε^{PSD}(coax) = $\varepsilon^{MSE} \cdot \varepsilon^{\alpha}$ = (79 ± 5)%

GERDA Collaboration meeting
Ringberg Castle **Jun 17th 2016**

LIVE UNBLINDING OF DATA IN
$Q_{\beta\beta} \pm 25$ keV

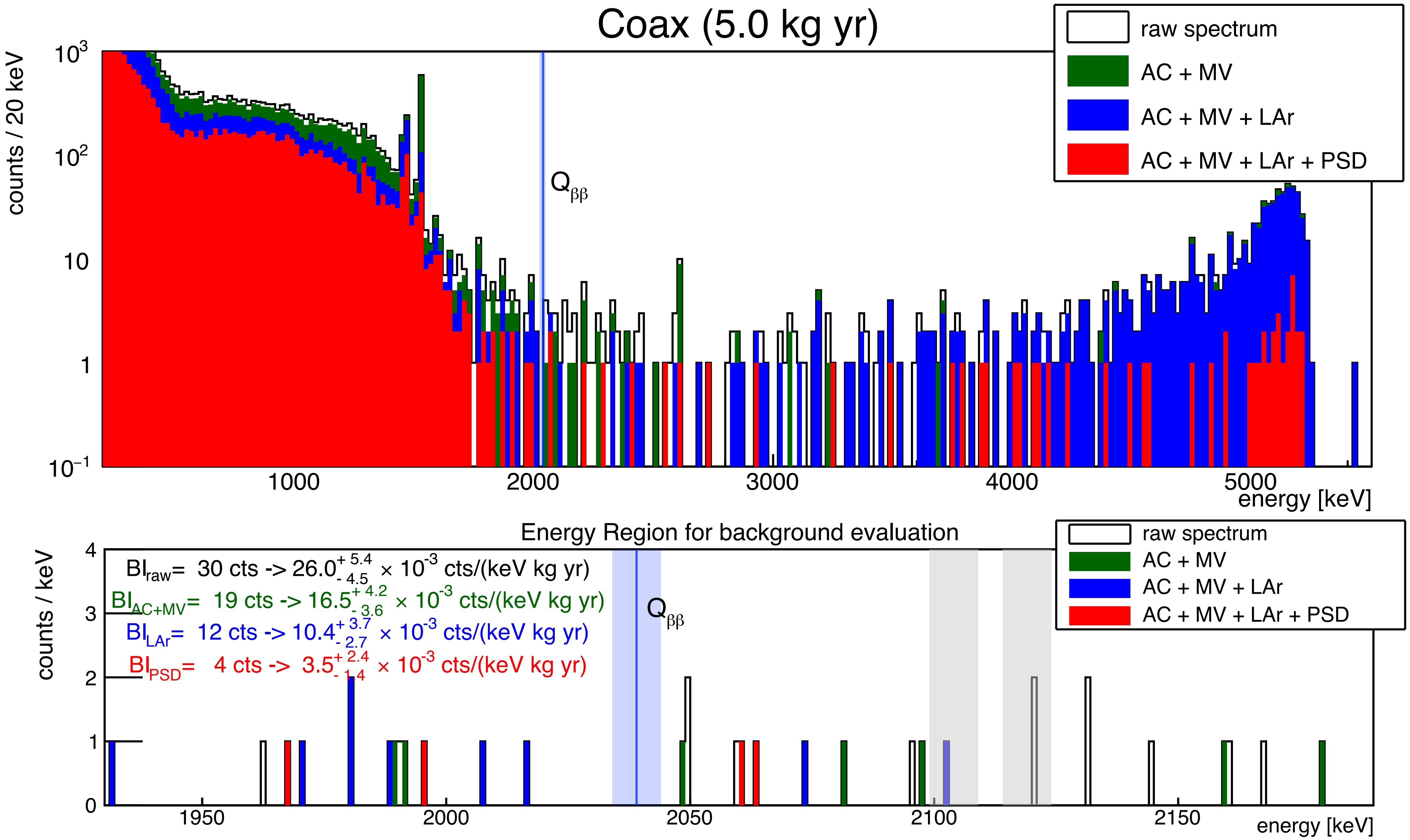
Unblinded Spectrum : Coaxials



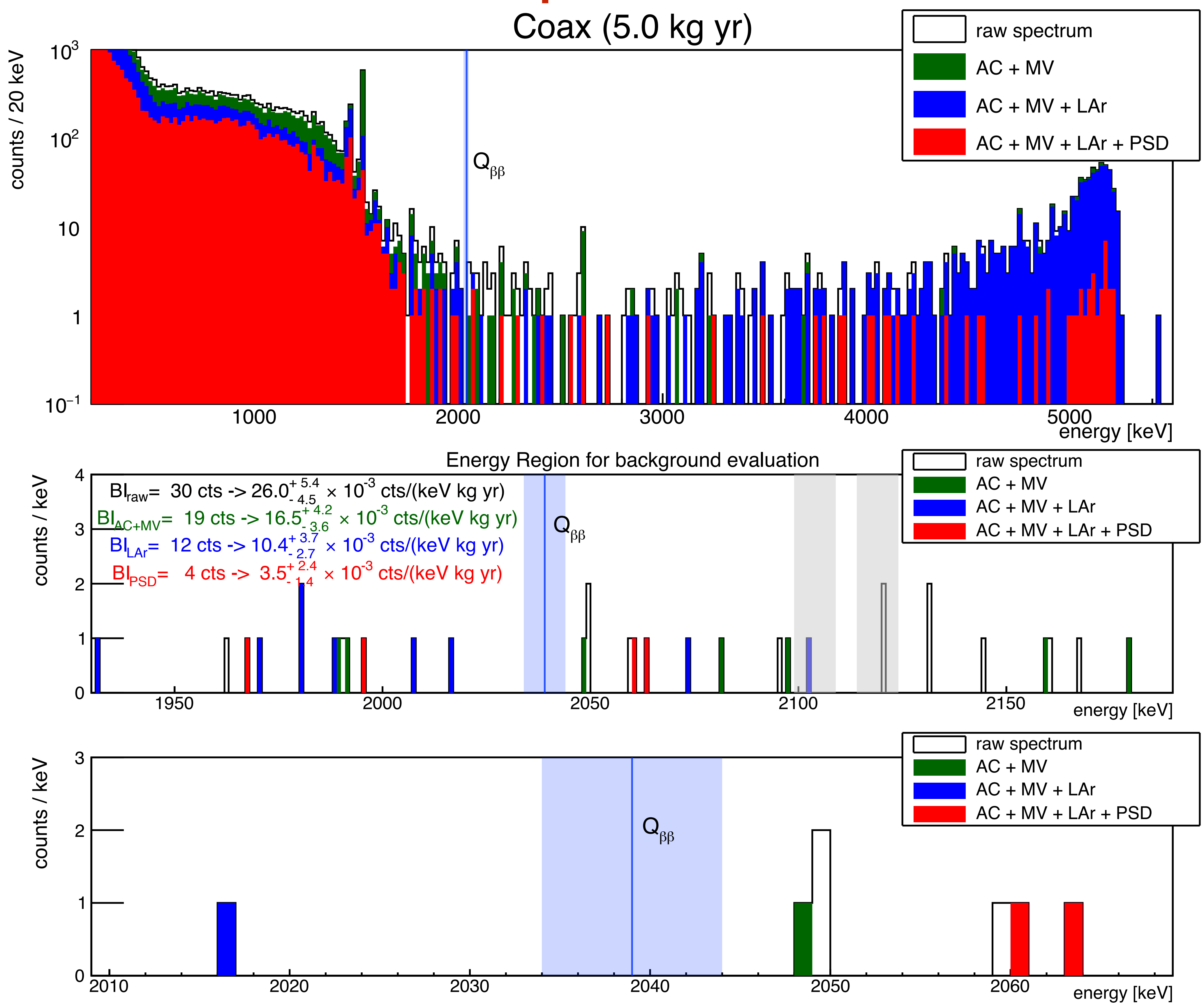
LEGEND

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

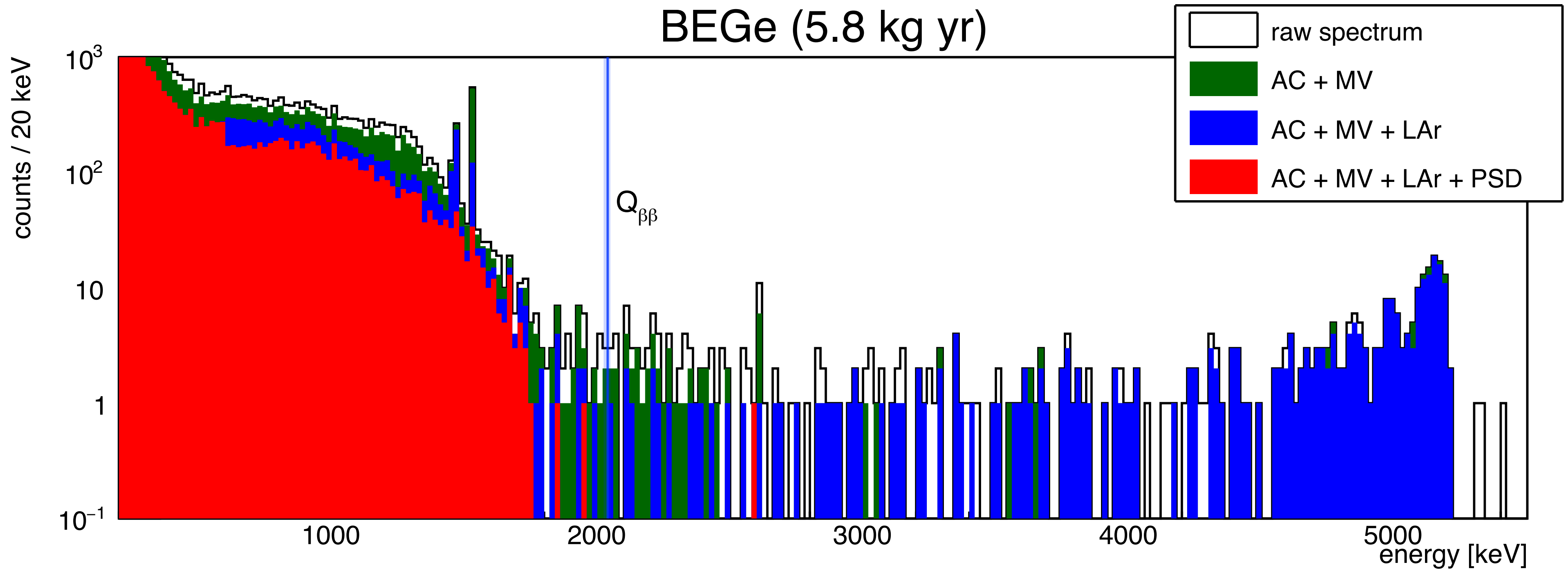
Unblinded Spectrum : Coaxials



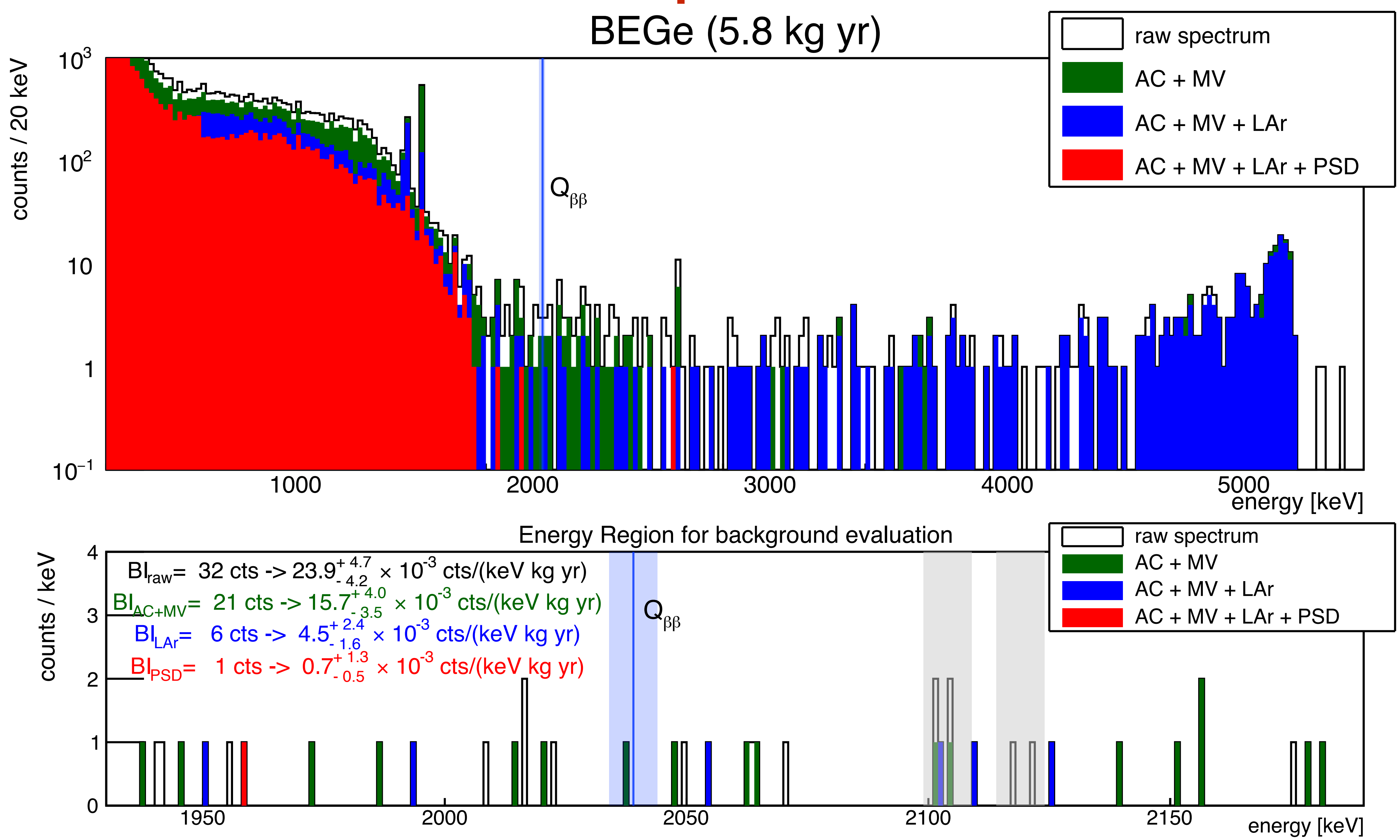
Unblinded Spectrum : Coaxials



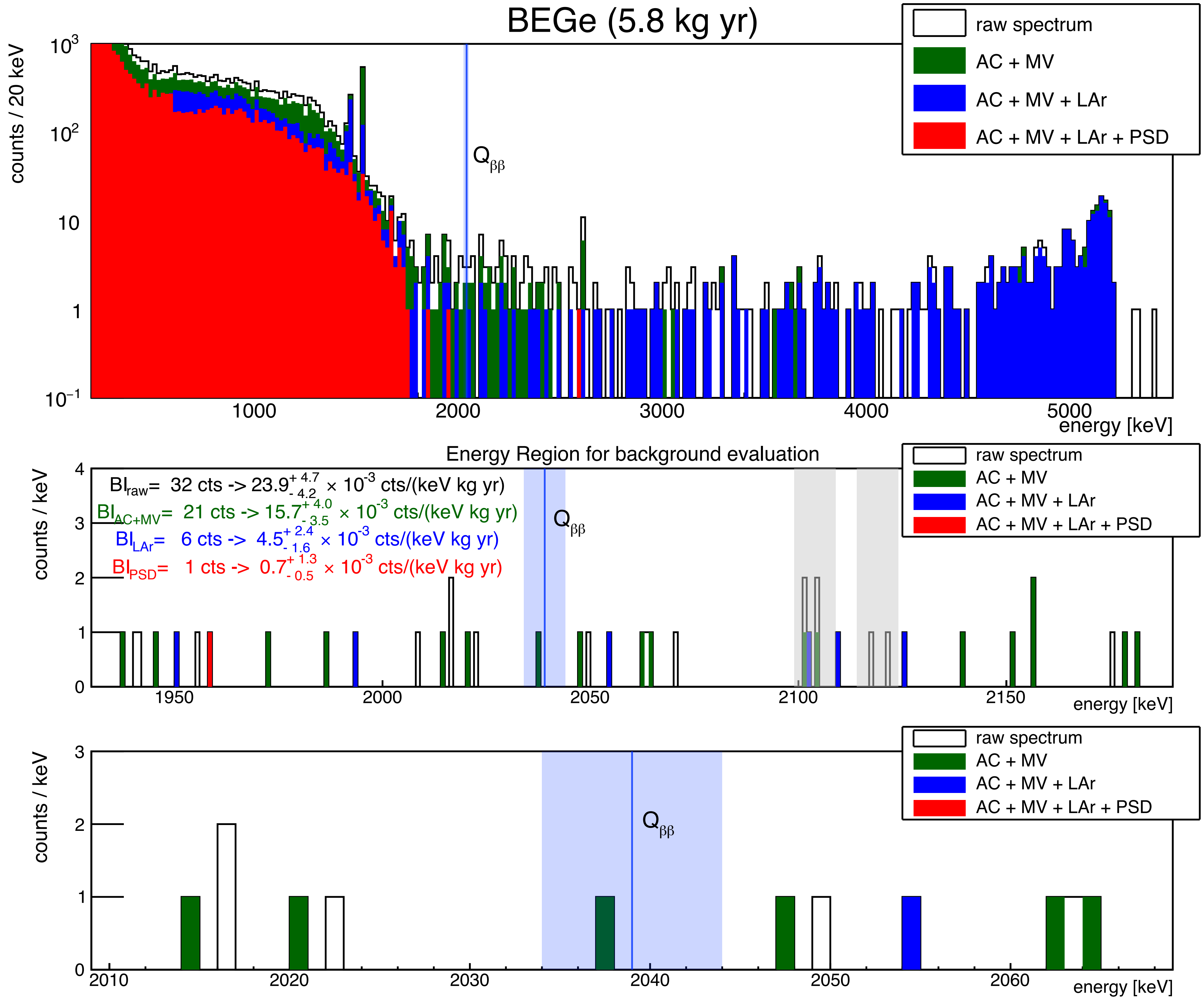
Unblinded Spectrum : BEGe



Unblinded Spectrum : BEGe



Unblinded Spectrum : BEGe



Background Analysis

data sets	esposure [kg · yr]	FWHM [keV]	efficiency	background [cts/(keV · kg · yr)]
Phase I - golden	**17.9**	4.3 (1)	0.57 (3)	$11 \pm 2 \cdot 10^{-3}$
Phase I - silver	**1.3**	4.3 (1)	0.57 (3)	$30 \pm 10 \cdot 10^{-3}$
Phase I - BEGe	**2.4**	2.7 (2)	0.66 (2)	$5^{+4}_{-3} \cdot 10^{-3}$
Phase I - extra	**1.9**	4.2 (2)	0.57 (3)	$5^{+4}_{-3} \cdot 10^{-3}$
Phase IIa - coaxial	**5.0**	4.0 (2)	0.53 (5)	$3.5^{+2.1}_{-1.5} \cdot 10^{-3}$
Phase IIa - BEGe	**5.8**	3.0 (2)	0.60 (2)	$0.7^{+1.1}_{-0.5} \cdot 10^{-3}$

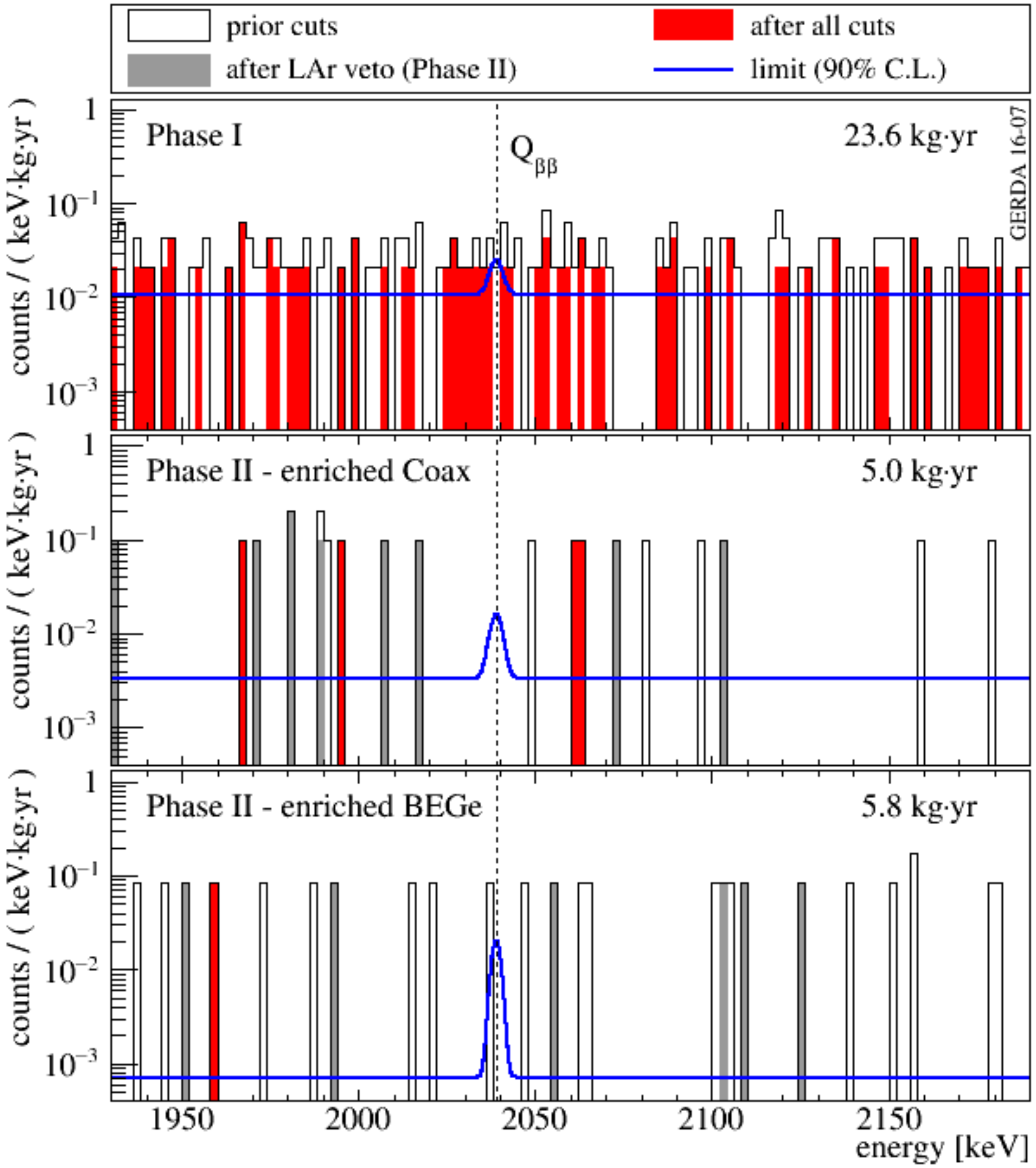
In addition to Phase II data:

- **Phase I extra** (after PRL), unblinded together with Phase II data sets
- **Phase I**, with improved resolution [EPJC 75 (2015) 255]

the efficiency includes active volume fraction, enrichment, reconstruction of $0\nu\beta\beta$, PSD efficiency, LAr veto loss

$T^{0\nu}_{1/2}$ results

	Profile likelihood 2-side test-stat	Bayesian flat prior
0νββ cts best fit value	0	0
$T^{0\nu}_{1/2}$ lower limit	> 5.2 · 10^{25} yr (90% C.L)	> 3.5 · 10^{25} yr (90% C.L)
$T^{0\nu}_{1/2}$ median sensitivity	4.0 · 10^{25} yr (90% C.L)	3.0 · 10^{25} yr (90% C.L)



- **Unbinned profile likelihood:** flat background (1930-2190 keV) + Gaussian signal
- frequentist test-statistics and methods [EPJC 71 (2011) 1554]

Conclusions and Summary

- GERDA Phase II is running stable since December 2015
- energy resolution at $Q_{\beta\beta}$ of 3-4 keV
- the lowest background ever achieved:
  - COAX: $3.5^{+2.1}_{-1.5} \cdot 10^{-3}$ [cts/(keV · kg · yr)]
  - BEGe: $0.7^{+1.1}_{-0.5} \cdot 10^{-3}$ [cts/(keV · kg · yr)]
- Combined analysis Phase I + II (preliminary):
  - $T^{0\nu}_{1/2} > 5.2 \cdot 10^{25}$ yr (90% CL)
  - $m_{\beta\beta} <$ 0.15 - 0.33 eV (90% CL)

GOAL:

- reach 100 kg · yr of exposure
- improve the limits on $T^{0\nu}_{1/2} \sim 10^{26}$ yr
- on $m_{\beta\beta} \sim 0.1$ eV