Searching for the neutrinoless double beta decay
- Phase II of the GERDA experiment -

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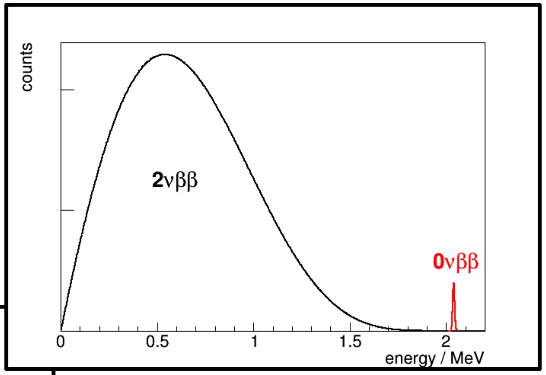
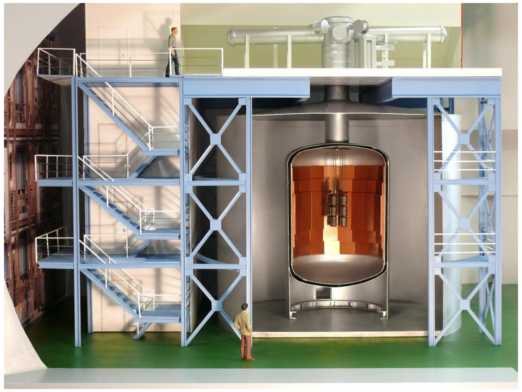
for the GERDA Collaboration

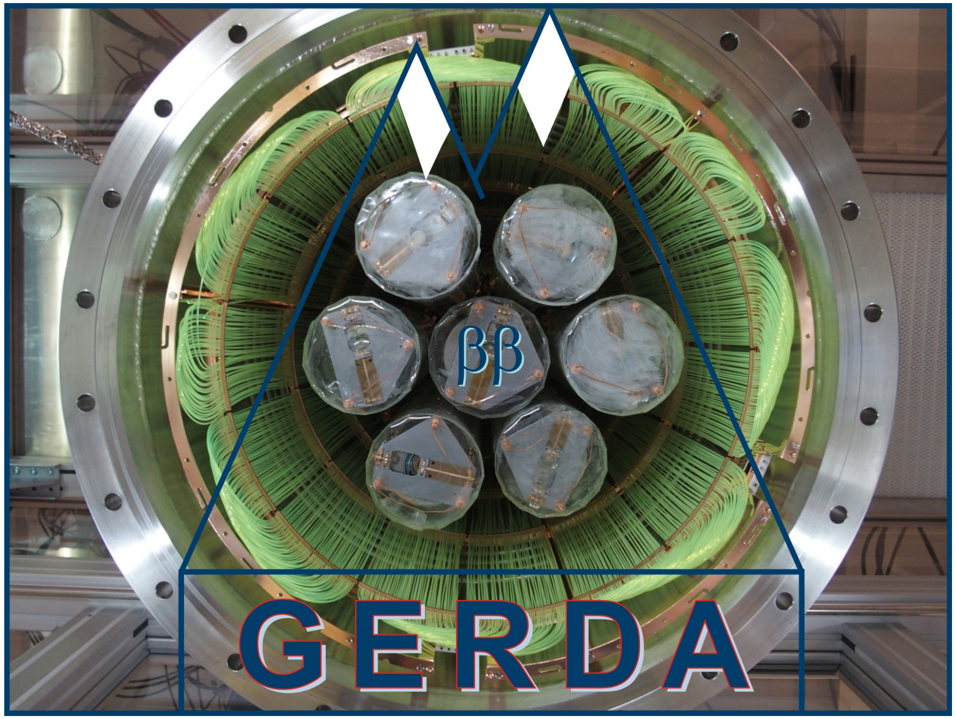
ICNFP2016, July 8th, 2016, Crete

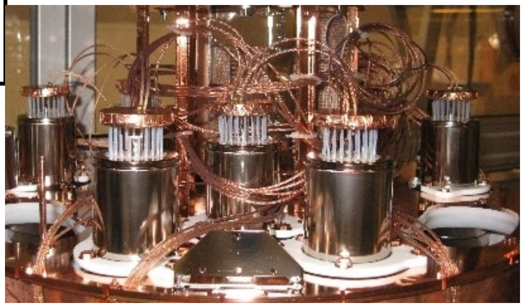
Content





- Neutrinoless double beta decay
- The GERDA experiment
- First data and results from Phase II
- Summary



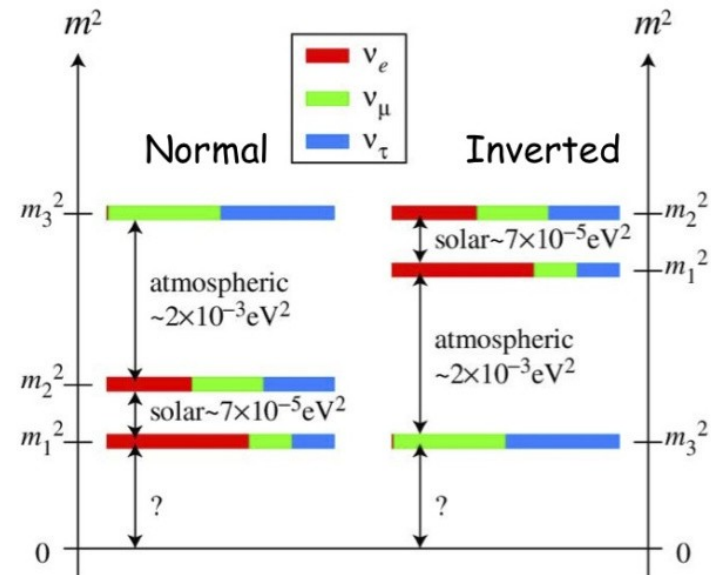


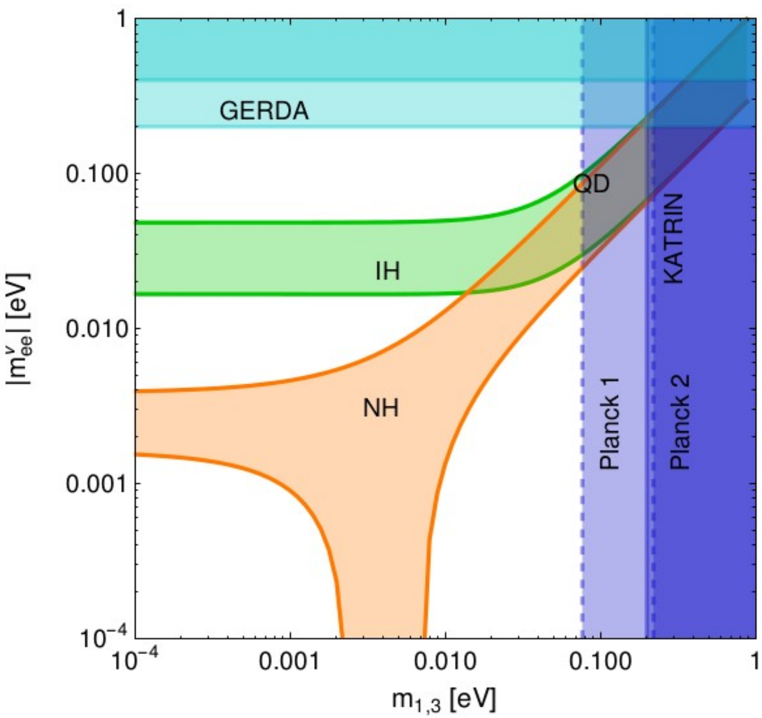
Introduction: Neutrinos

- neutrino masses ≠ 0
- difference of squared masses measured by oscillation experiments, but...
- …absolute mass scale unknown
- normal ($m_3 > m_1, m_2$)

  or inverted ($m_3 < m_1, m_2$) hierarchy?
- Majorana nature of neutrinos?

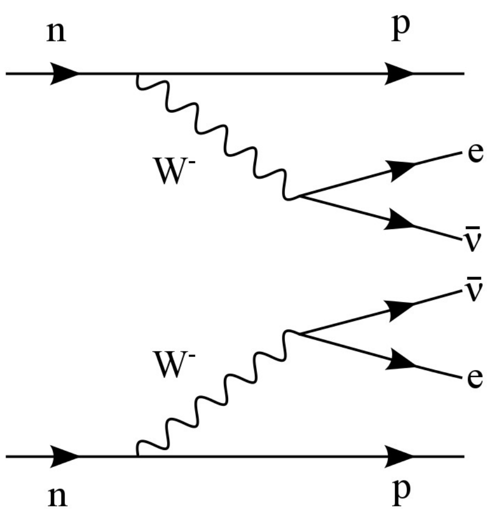
? ? ? ν ? ? ?

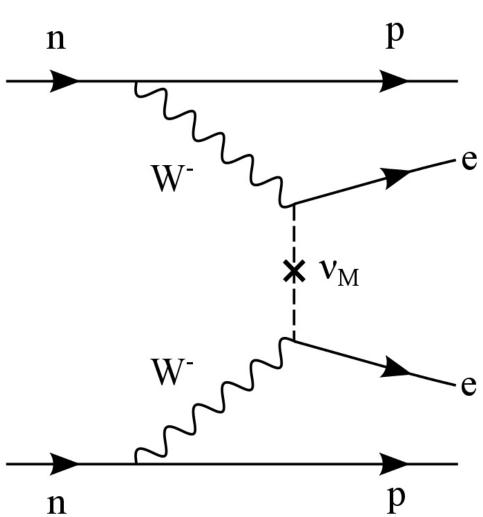


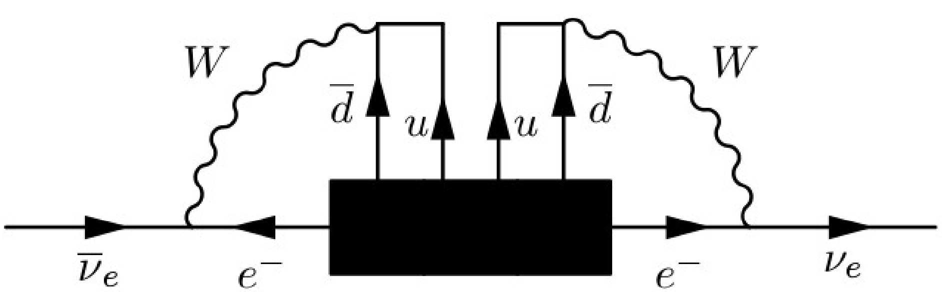


arXiv1508.07286

Introduction: Double beta decay







Neutrino accompanied ββ-decay (2νββ)

- second order weak decay allowed in the Standard Model
- observed in 12 isotopes
- half-life ~ 10^{18}-10^{24} yr

Neutrinoless ββ-decay (0νββ)

- violates lepton number conservation → new physics
- Majorana mass term for neutrinos (independent of mechanism)
- leads to information about absolute mass scale of neutrinos (in case of light Majorana neutrino exchange)

$$m_{\beta\beta} = \sum_{i=0}^{3} U_{ei}^2 \cdot m_i$$

- half-life limits > 10^{25} yr

Introduction: Experimental parameters

sensitivity estimation (in presence of background):

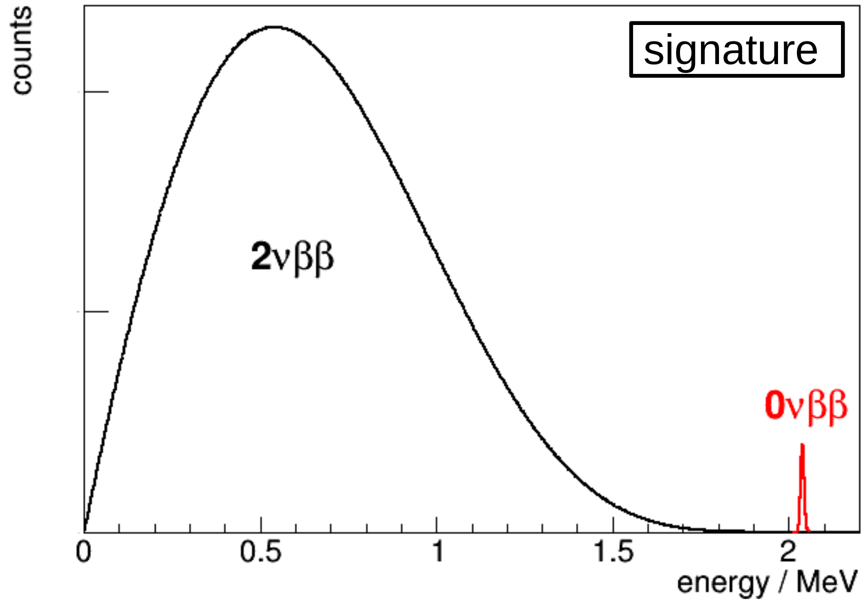
$$T_{1/2} \propto \varepsilon \cdot a \cdot \sqrt{\frac{M \cdot t}{BI \cdot \Delta E}}$$

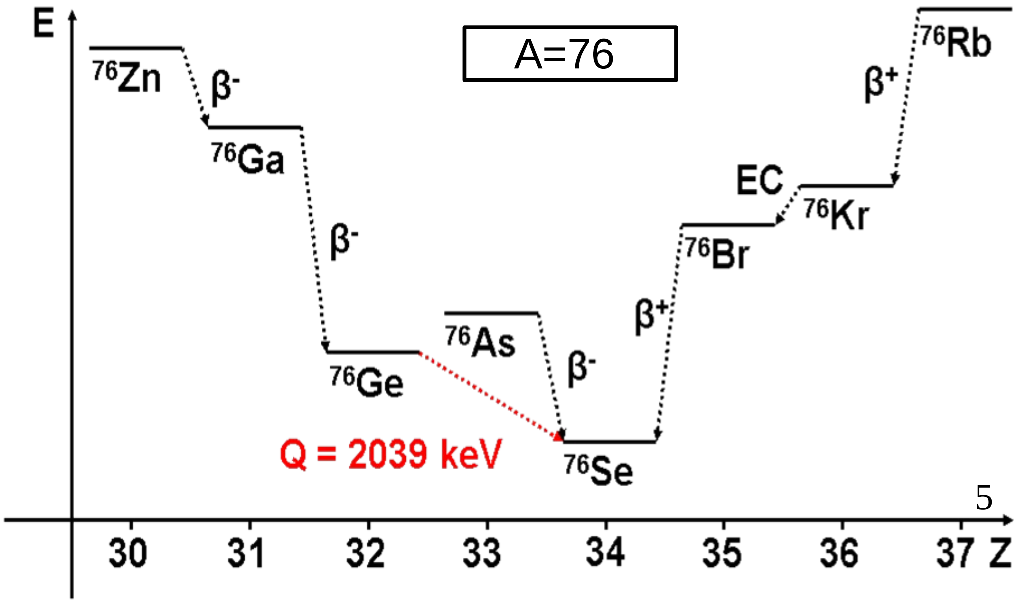
ε … signal efficiency (source = detector)

a … abundance (source enriched in isotope of interest)

BI … background index (underground location, ultra-pure material,...)

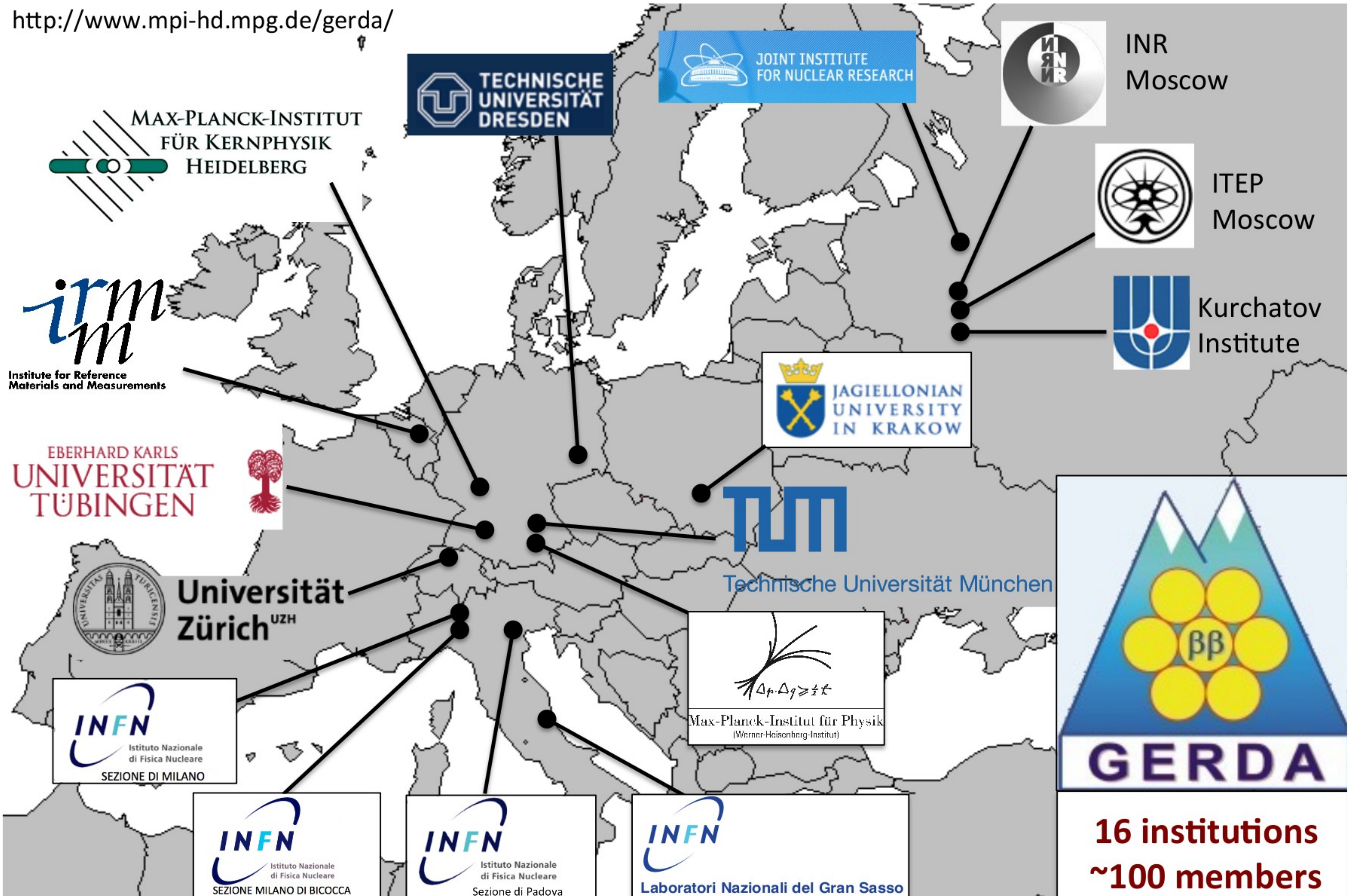
Δ*E* … energy resolution, *M* … source mass, *t* .. experiment livetime





The GERDA collaboration

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



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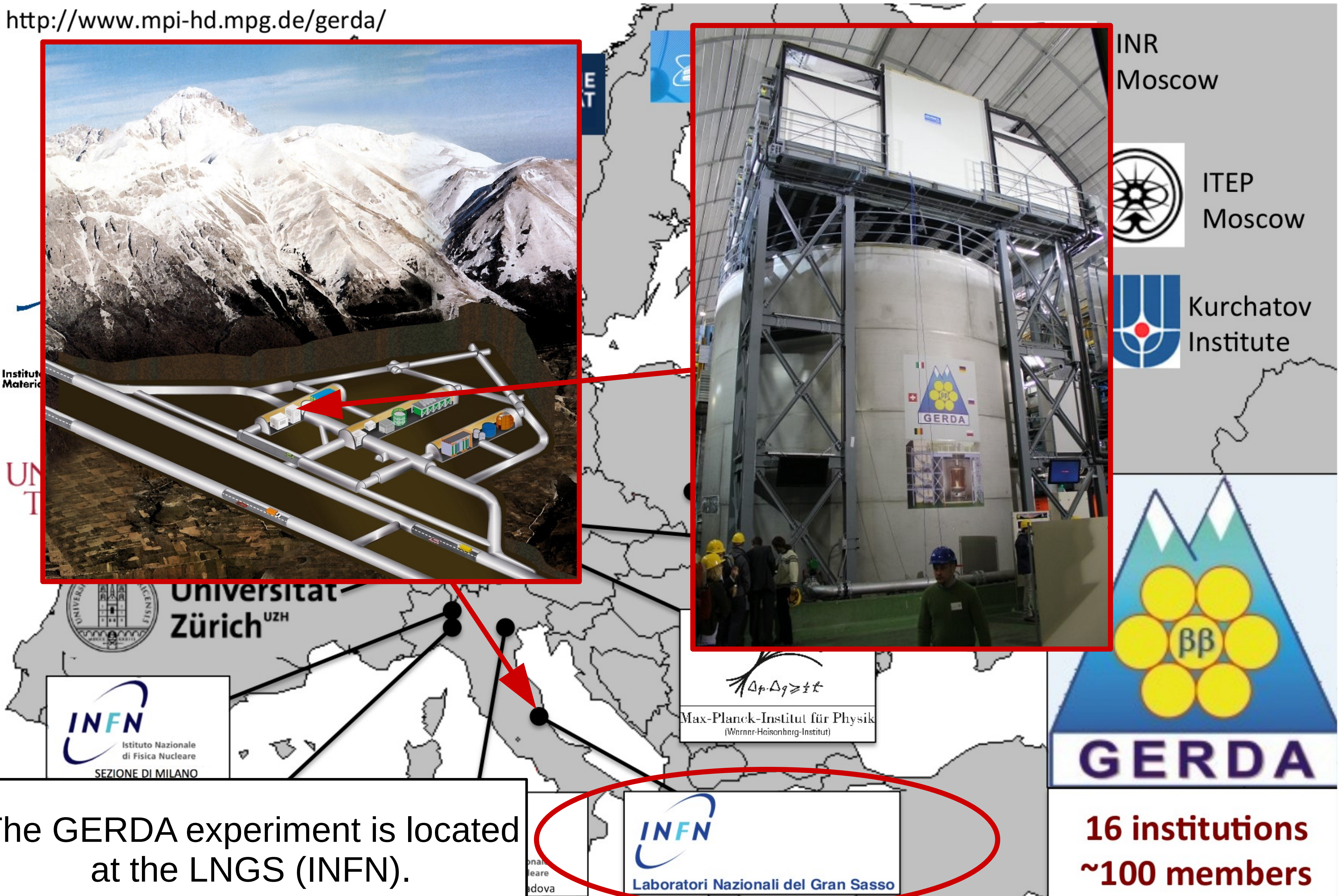
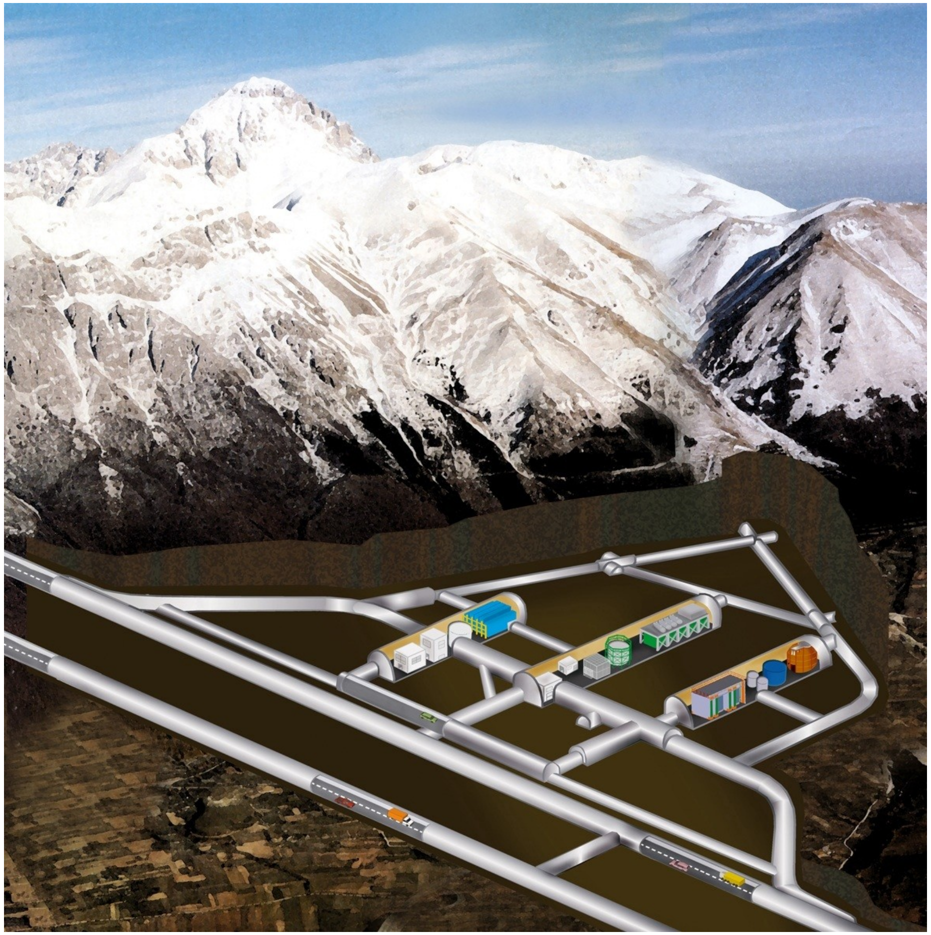


16 institutions
~100 members

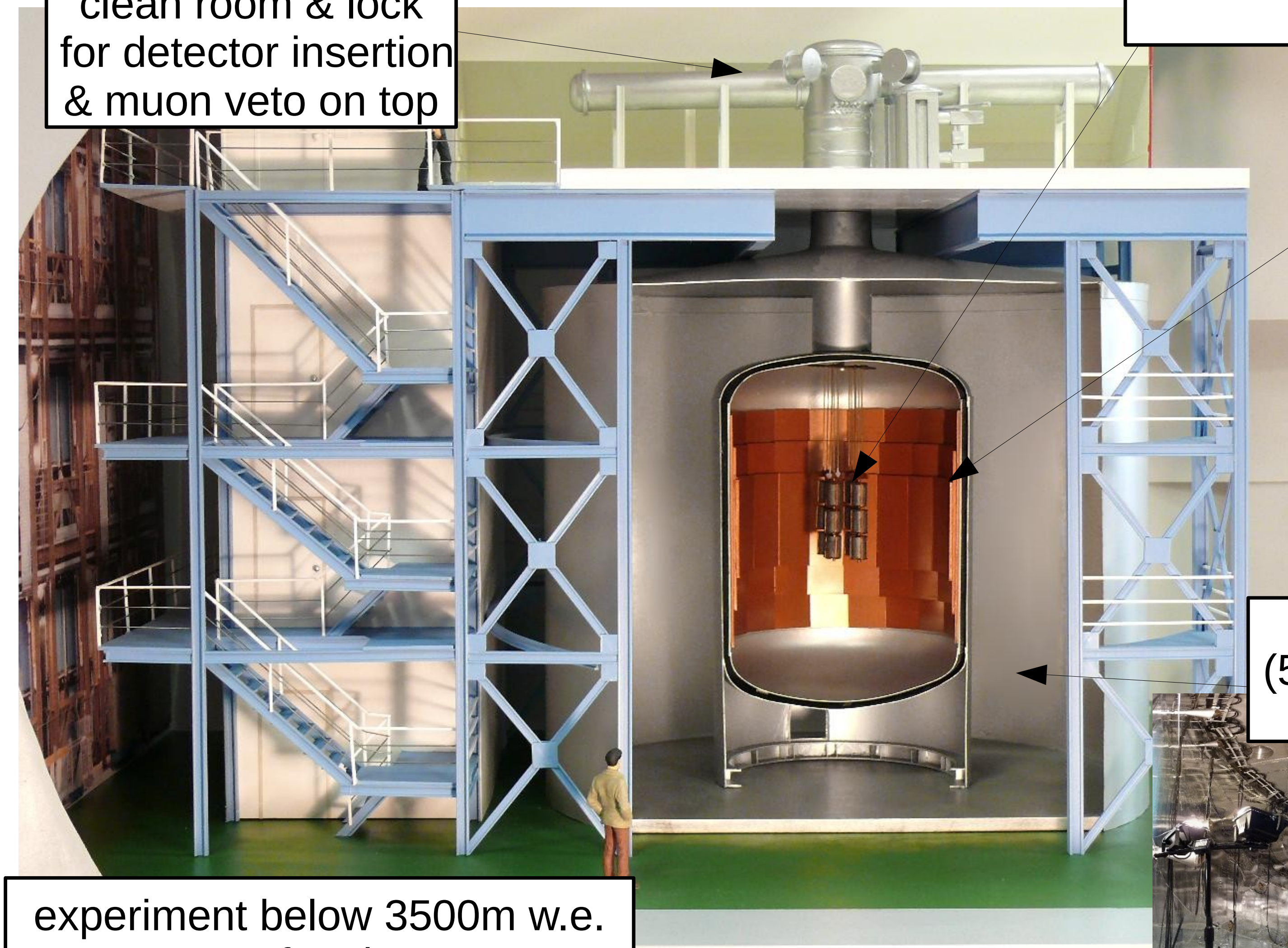
The GERDA experiment is located at the LNGS (INFN).

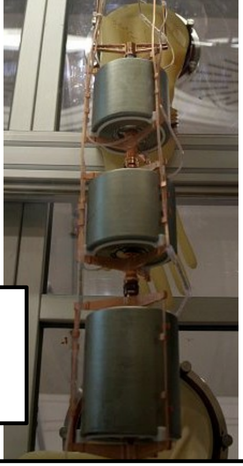
The experiment



GERDA – GERmanium Detector Array

- inauguration: 9th of November 2010





clean room & lock
for detector insertion
& muon veto on top

detector strings

cryostat
64 m³ LAr

water tank
(590 m³ pure water)
muon veto

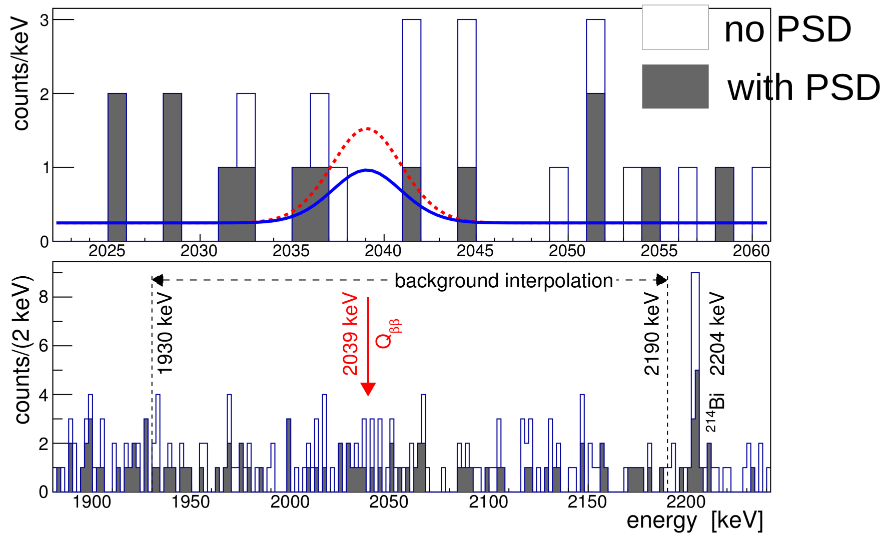
experiment below 3500m w.e.
of rock

Eur. Phys. J. C 73 (2013) 2330

GERDA: 0νββ in ^{76}Ge – Phase I results

- sensitivity of $2.4 \cdot 10^{25}$ yr (90% C.L.) reached after 21.6 kg·yr of data
- BI ~ 0.01 cts/(keV·kg·yr)
- no signal found

  (3 events observed, 2.5 events expected)



- Frequentist:

  → $T_{1/2} > 2.1 \cdot 10^{25}$ yr (90% C.L.)

- Bayesian:

  → $T_{1/2} > 1.9 \cdot 10^{25}$ yr (90% C.I.)

- combined with previous Ge experiments:

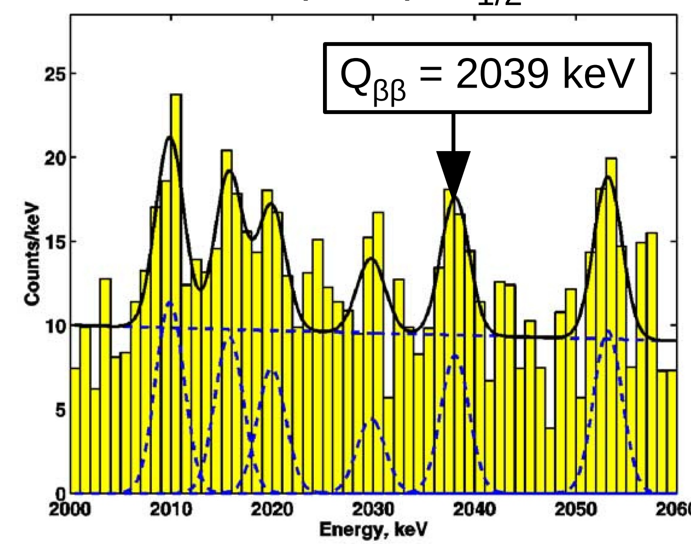
  → $T_{1/2} > 3.0 \cdot 10^{25}$ yr (90% C.L.)

  $m_{\beta\beta} < 0.2\text{-}0.4$ eV

Phys. Rev. Lett 111 (2013) 122503

Physics Letters B 586 (2004) 198-212

claim of evidence (4.2σ): $T_{1/2} = 1.19 \cdot 10^{25}$ yr

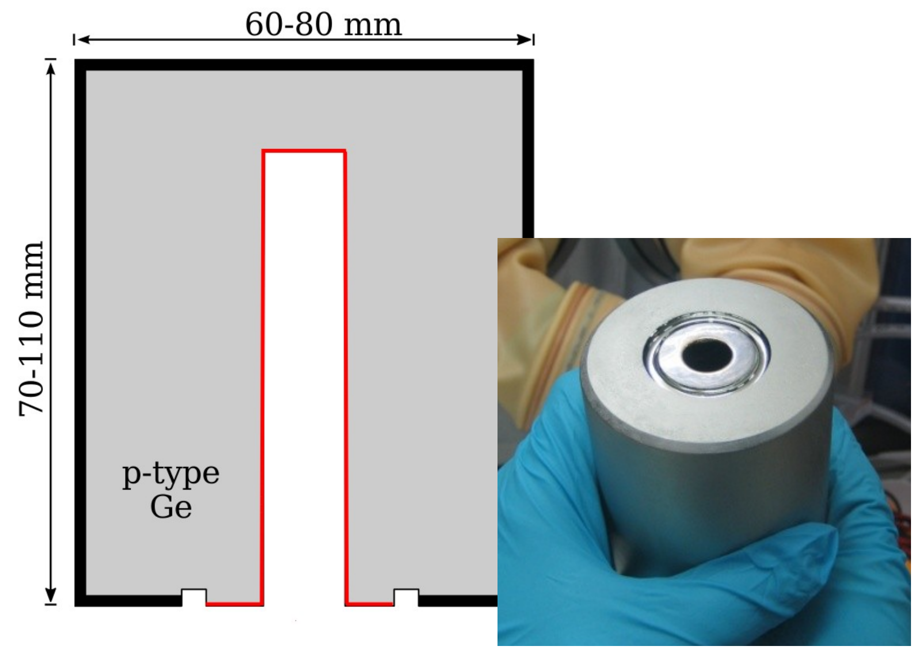


→ strongly disfavored by GERDA with 99% probability!

The detectors

11 coaxial detectors

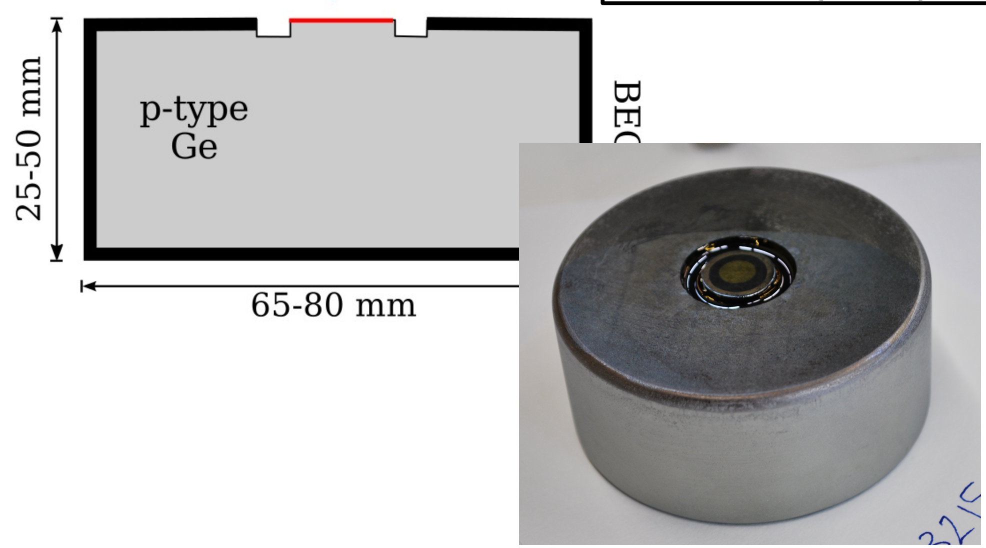
- 8 enriched in ^{76}Ge (~87%)
- refurbished from former experiments
- ~4 keV FWHM @ 2 MeV
- ~1-3 kg
- p^+ contact in borehole (deadlayer ~ µm)
- n^+ contact on outside (deadlayer ~ mm)



EPJC 75 (2015) 39

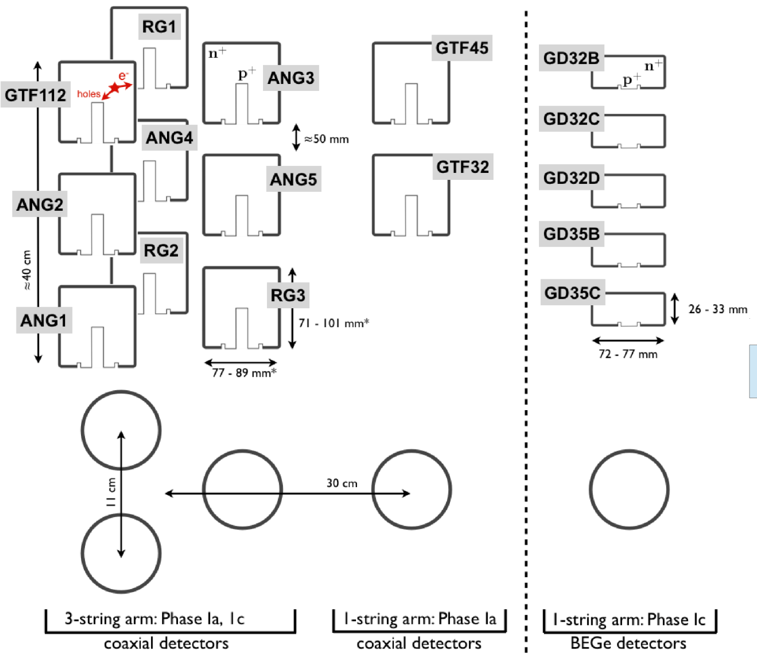
30 BEGe detectors

- all enriched in ^{76}Ge (~87%)
- 5 used as prototypes in Phase I
- ~3 keV FWHM @ 2 MeV
- ~0.4-0.8 kg
- much smaller p^+ contact
- improved pulse shape discrimination



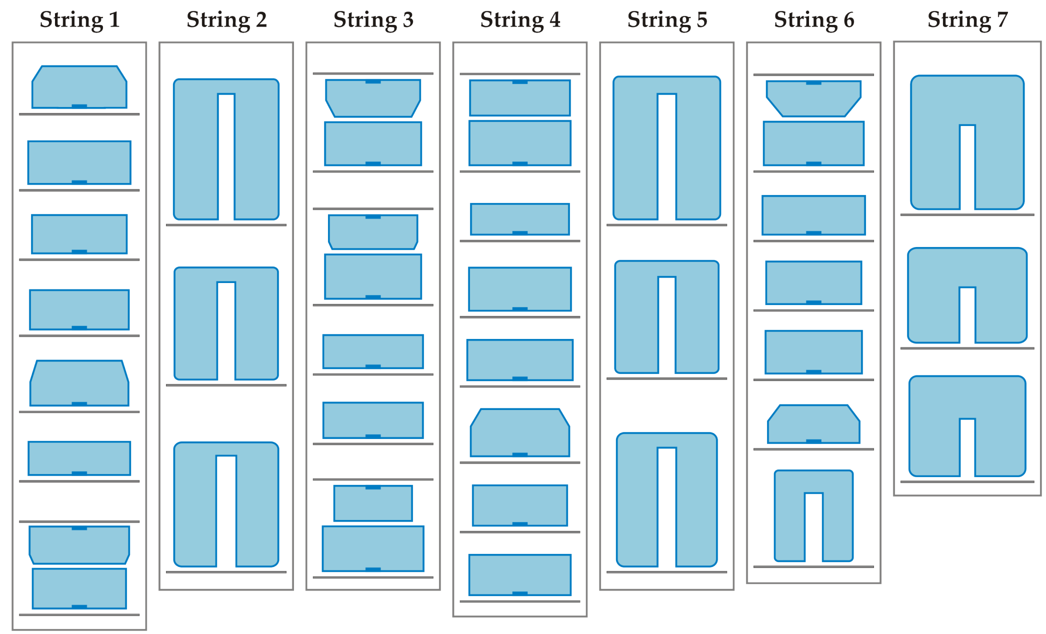
Detector array

Phase I

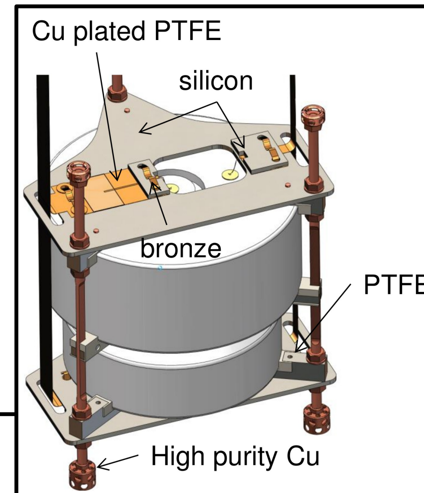


- 17.7 kg enriched coax
- 7.6 kg natural coax
- 3.6 kg enriched BEGe (2nd half)

Phase II

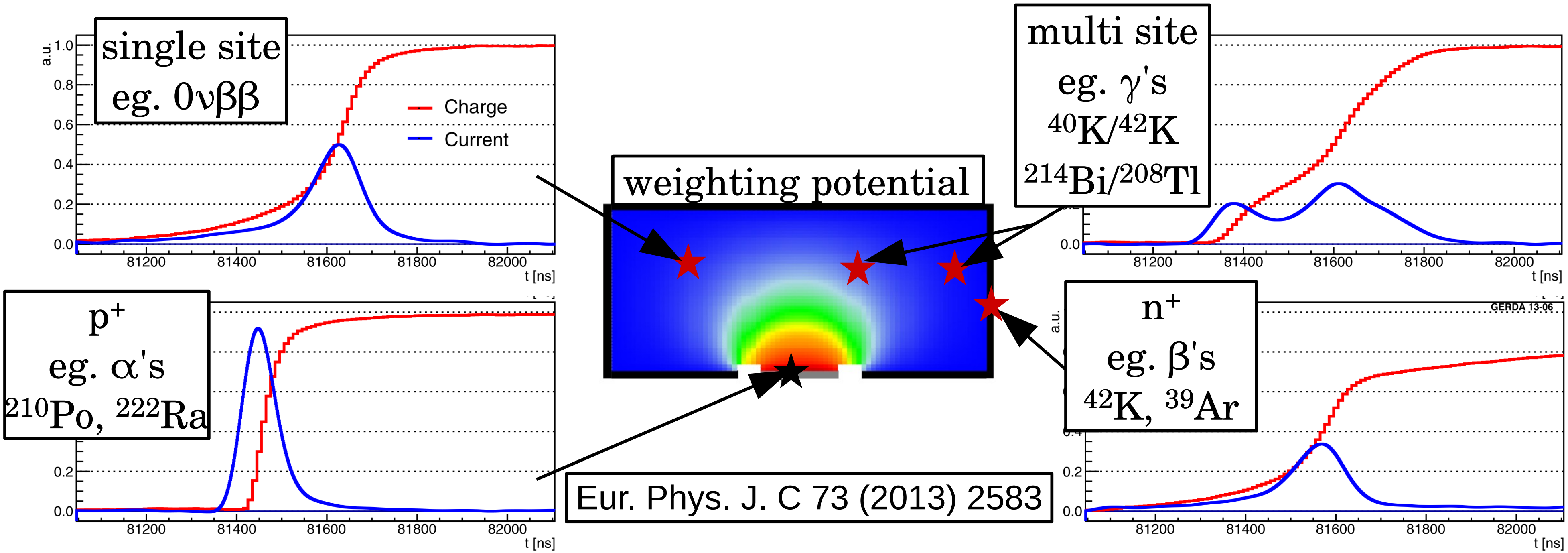


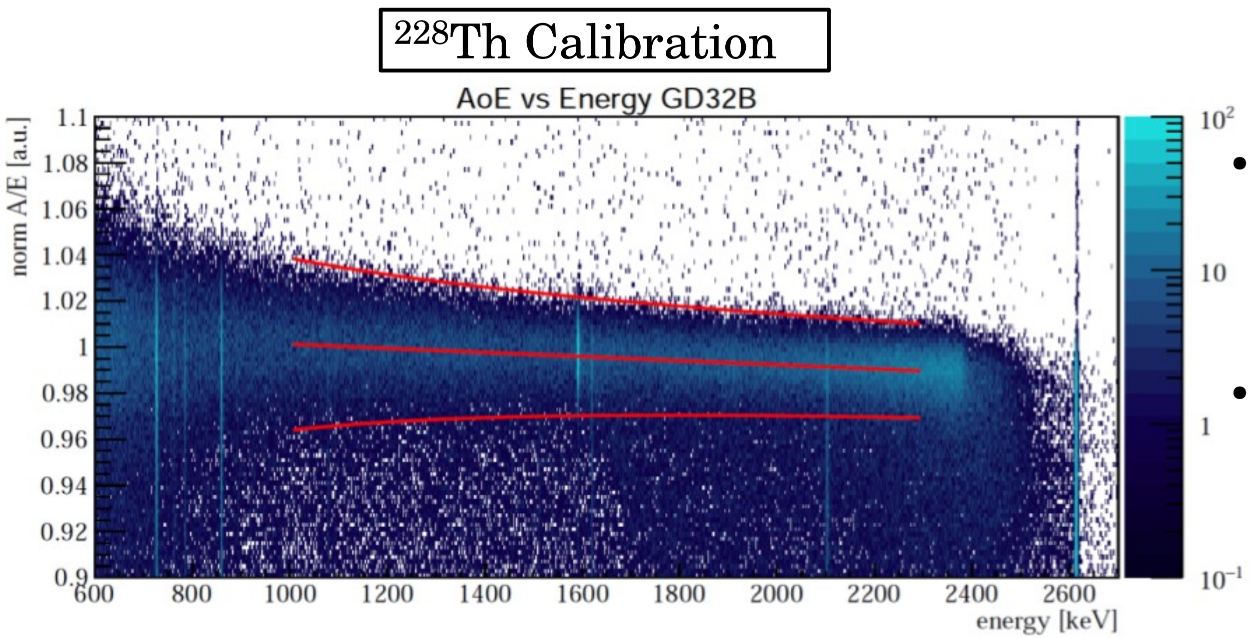
- new lower mass low-acitivity holder material & electronics
- 15.7 kg enriched coax
- 7.6 kg natural coax
- 20.0 kg enriched BEGe



→ source mass roughly doubled

Pulse shape discrimination (PSD) - BEGe

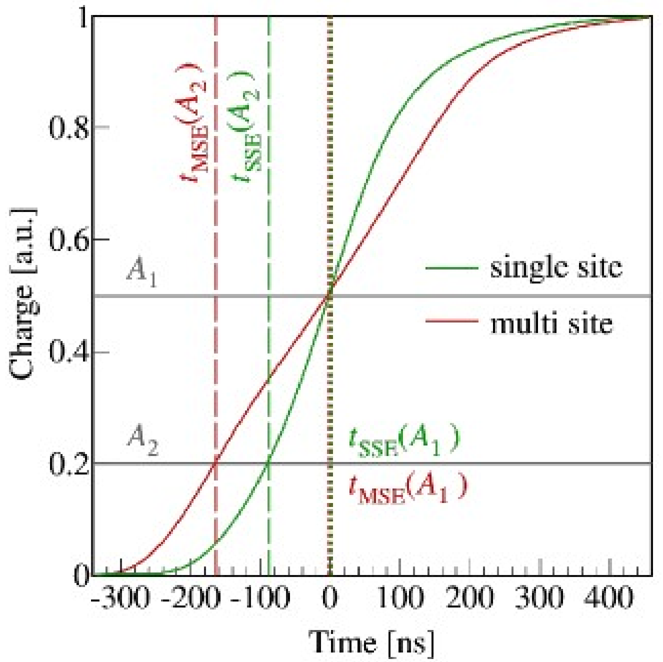




<u>A/E (Amplitude/Energy)</u>

- survival of 0νββ estimated with double escape peak:
  - DEP: ~90%
- survival multi-site events:
  - SEP: ~10%
  - Compton at 2MeV: ~40%

Pulse shape discrimination (PSD) - Coax

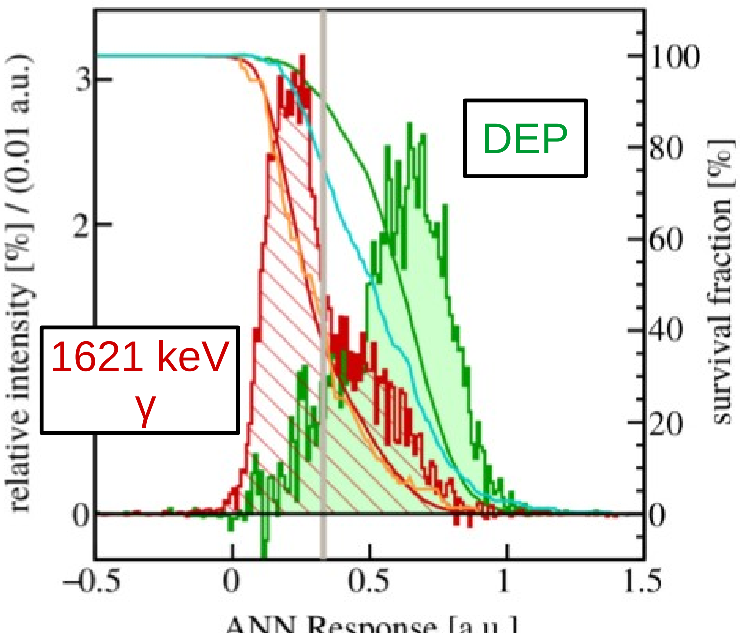


ANN – Artificial Neural Network

- depending on interaction point, single-site pulse shapes look different
- train network with DEP events as signal samples

  and ^{212}Bi 1621 keV γ-ray events as background samples
- 50 timestamps, where the pulse shape reaches 1%, 3%, …, 99% of maximum

Eur. Phys. J. C 73 (2013) 2583



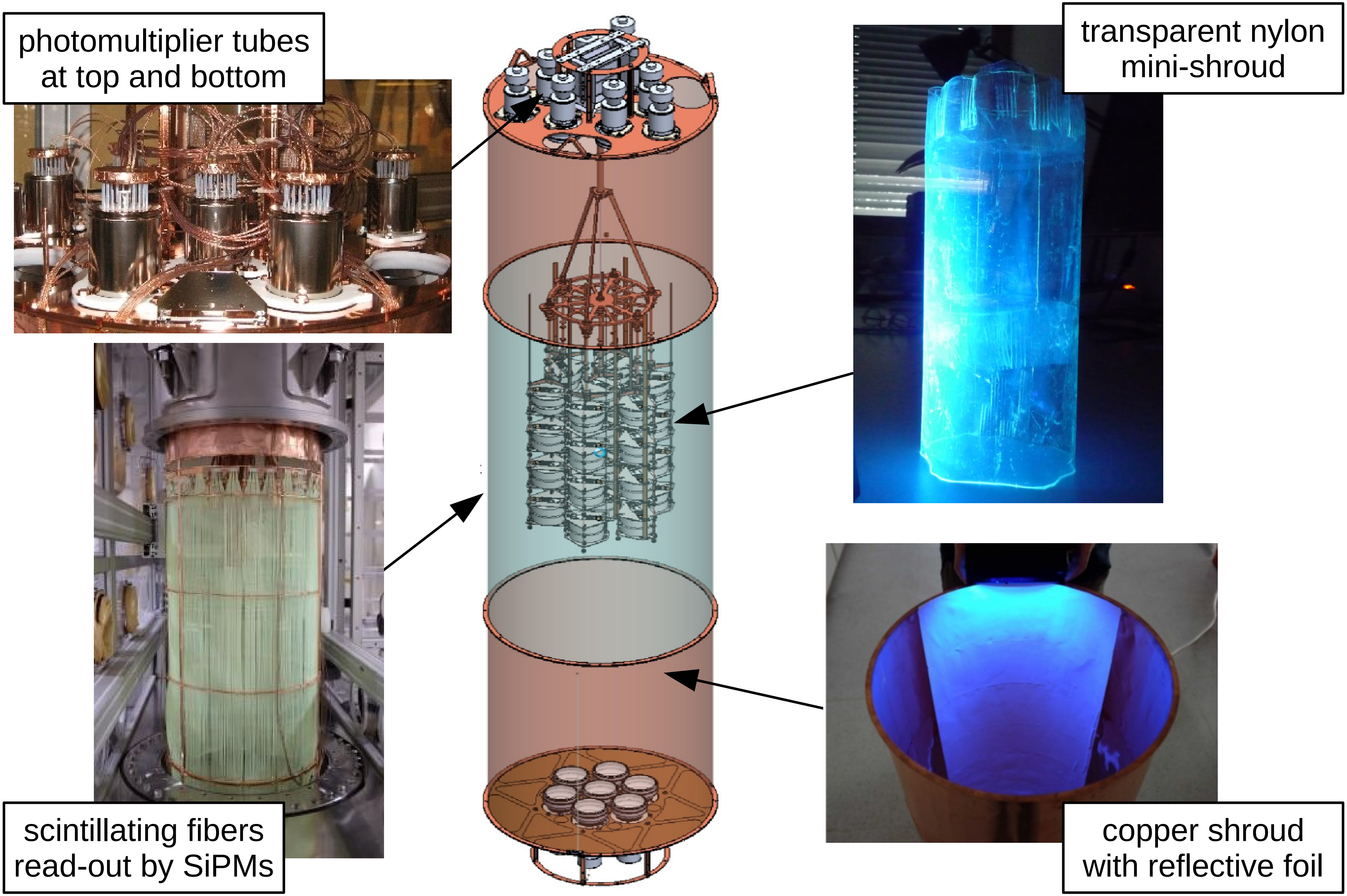
- background survival fraction:

  ~40% at ^{212}Bi γ-ray, ~60% for compton at 2 MeV
- 0νββ survival: (80±9)%

  Preliminary! Uncertainty, will be reduced after further crosschecks

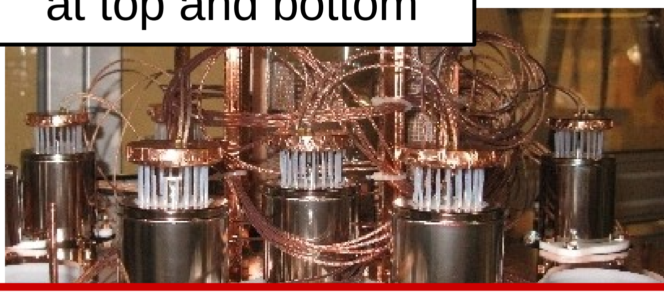
also discrimination of alpha events with separate training (10% alphas, ~95% signal survival)

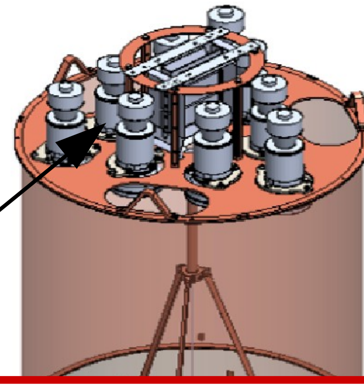
LAr active scintillation veto (new in Phase II)



LAr active scintillation veto (new in Phase II)

photomultiplier tubes
at top and bottom





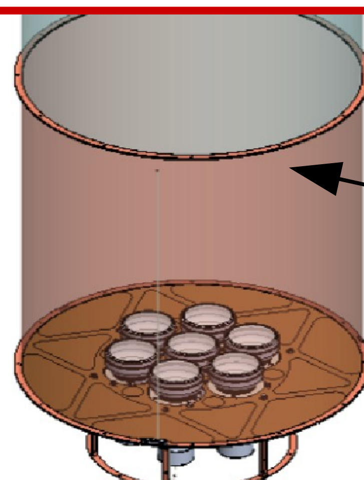
transparent nylon
mini-shroud

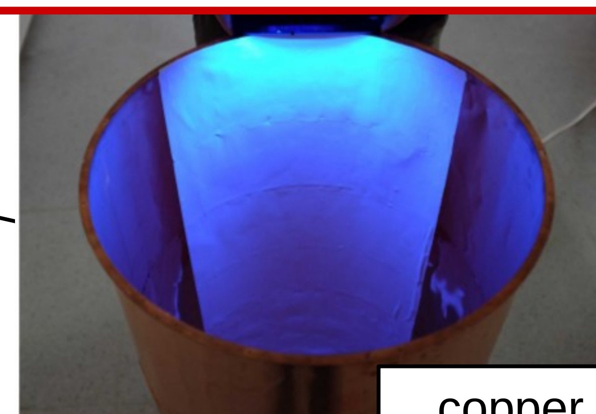
- suppression factors achieved with a single string during commissioning:

^{226}Ra calibration source		^{228}Th calibration source	
LAr veto:	~5	LAr veto:	~85
+ PSD + Anti-coincidence:	~25	+ PSD + Anti-coincidence:	~400

- suppression factor dependent on source isotope, location and array configuration

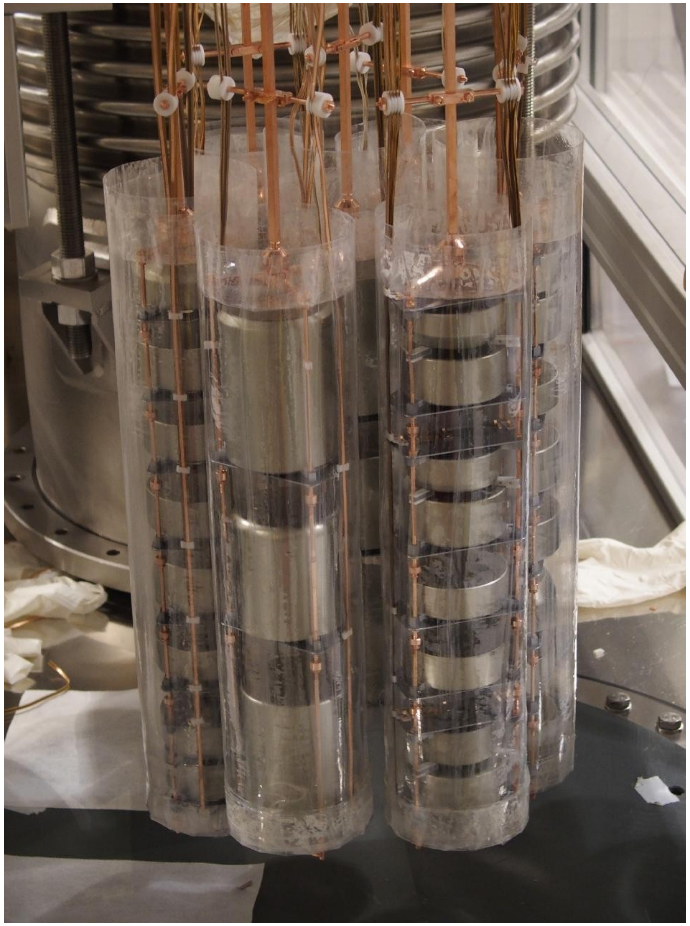
scintillating fibers
read-out by SiPMs



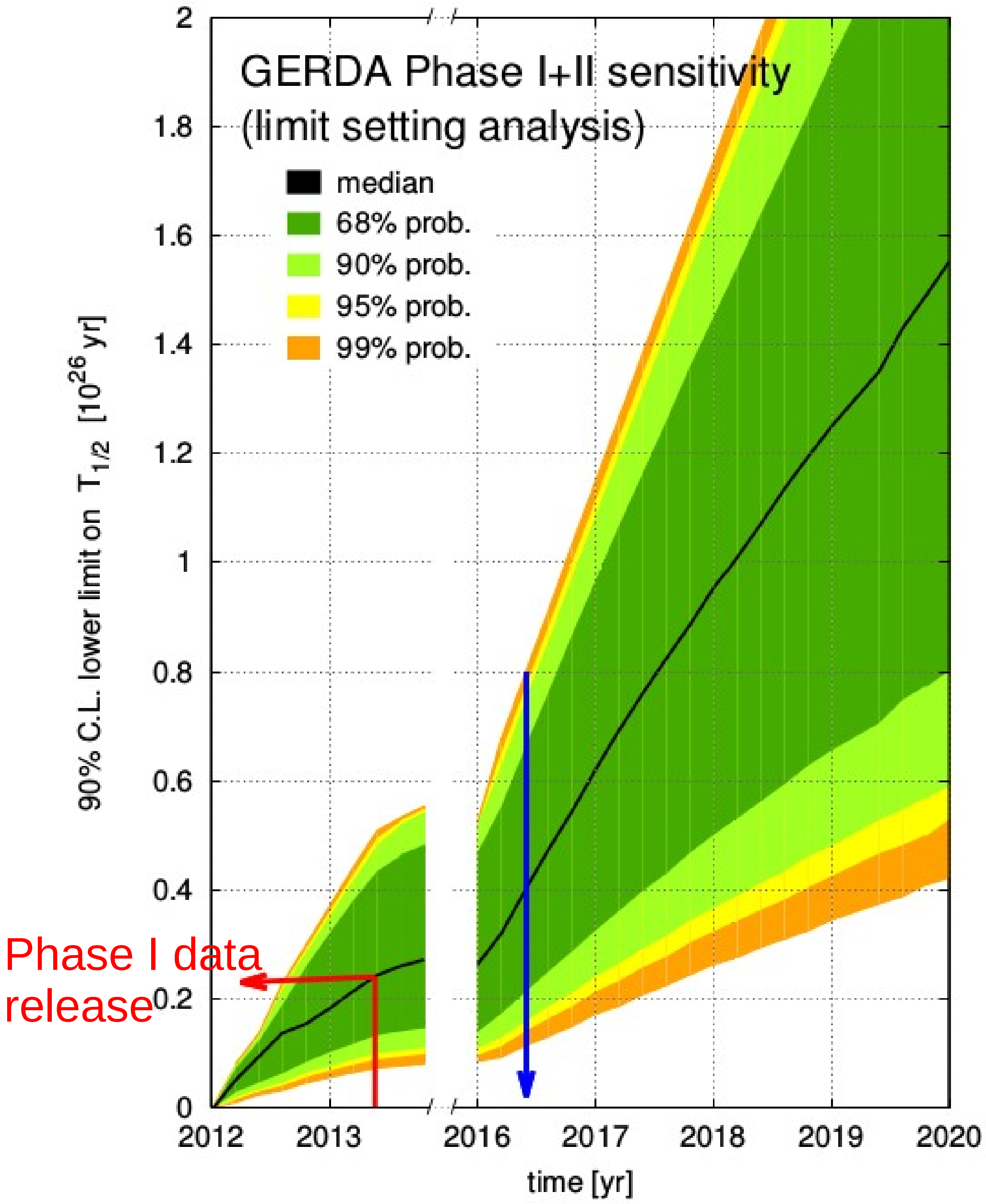


copper shroud
with reflective foil

Phase II – First data Dec 2015 – May 2016



Transition to Phase II



Phase II upgrades:

- more detectors

  ~ double the source mass

- improve BI by a factor of 10

  → 10^{-3} cts/(keV·kg·yr)

  via:

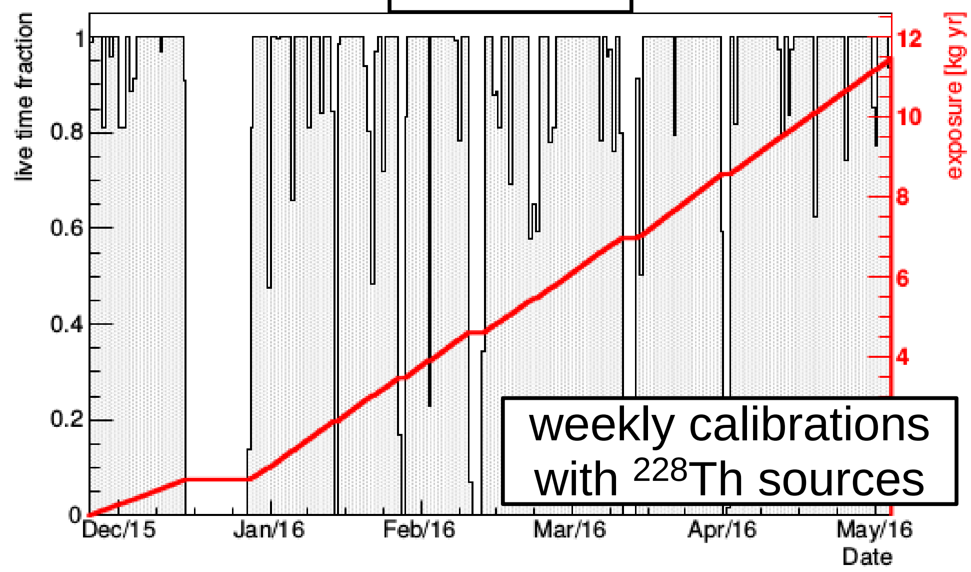
  - improved PSD
  - LAr instrumentation
  - less, more radiopure material for detector holders

first data release: ~$4 \cdot 10^{25}$ yr

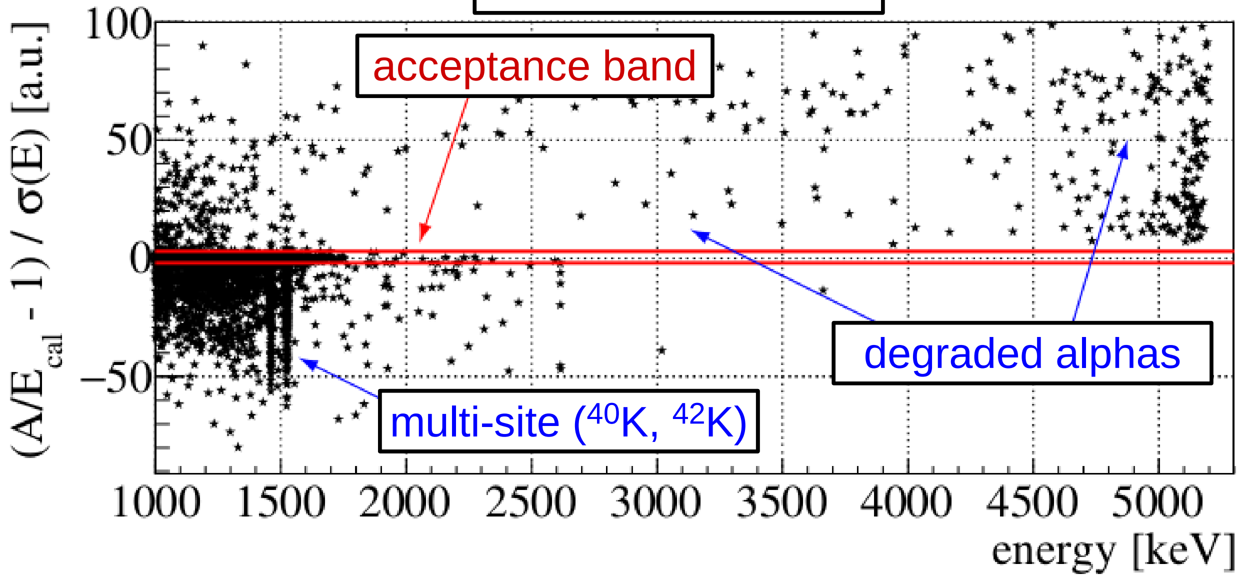
Phase II - First data release

- Dec 2015 – May 2016
- 82% average duty cycle
- exposure
  - 5.8 kgyr (BEGe)
  - 5.0 kgyr (Coax)
- data blinded in $Q_{\beta\beta}$ ± 25 keV

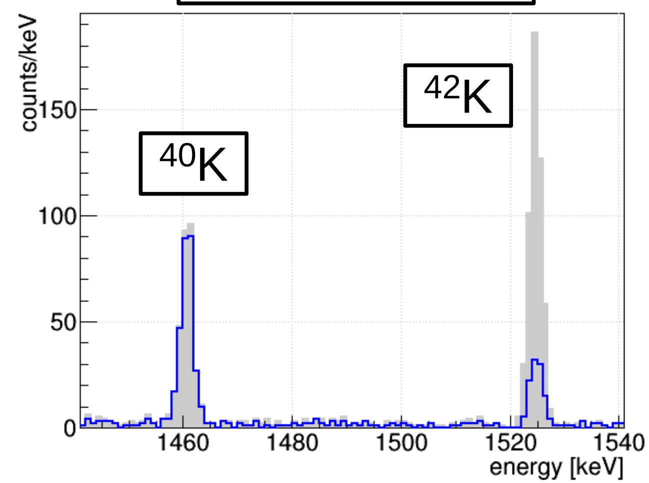
duty cycle



A/E of BEGe data

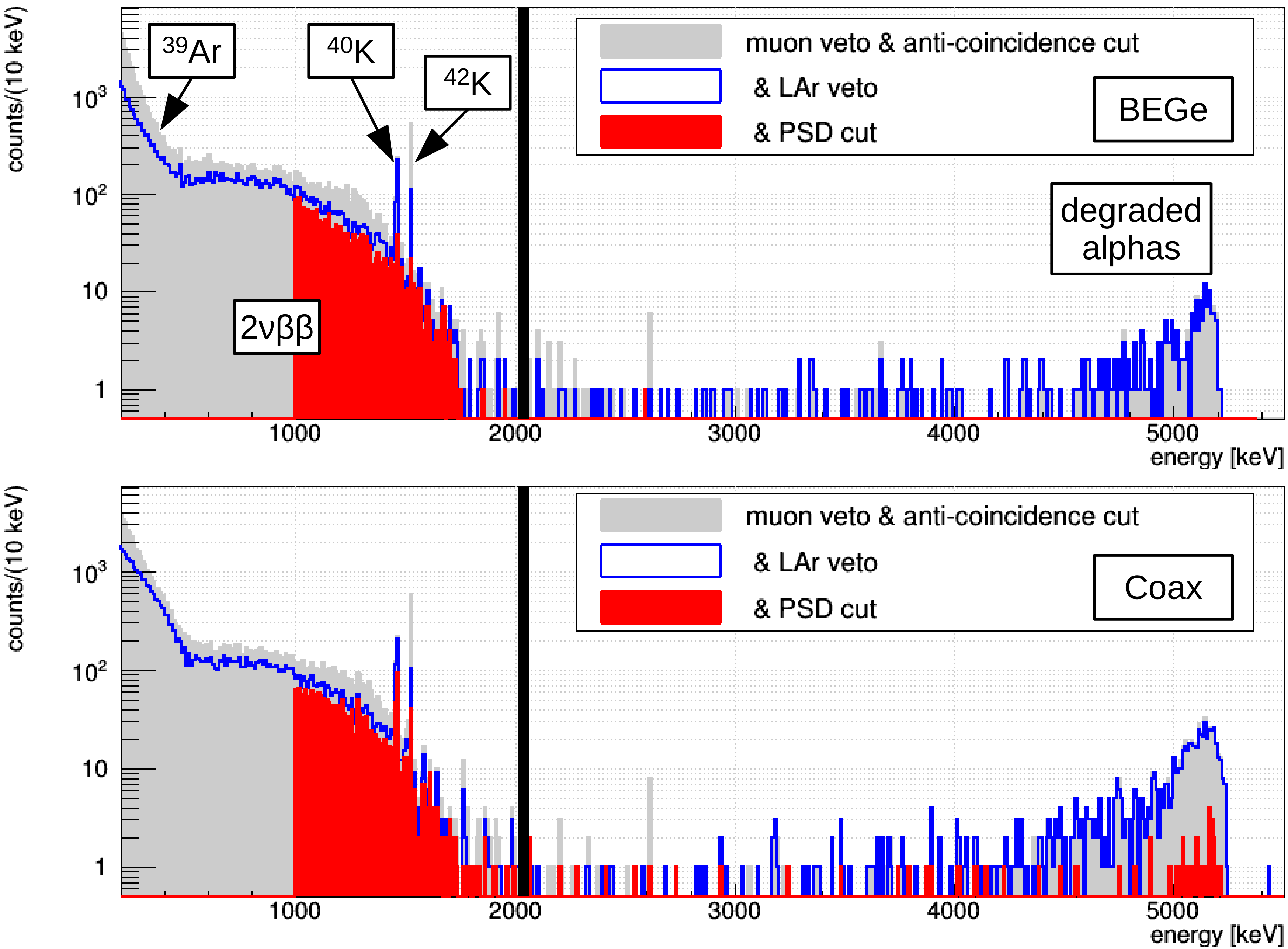


LAr suppression

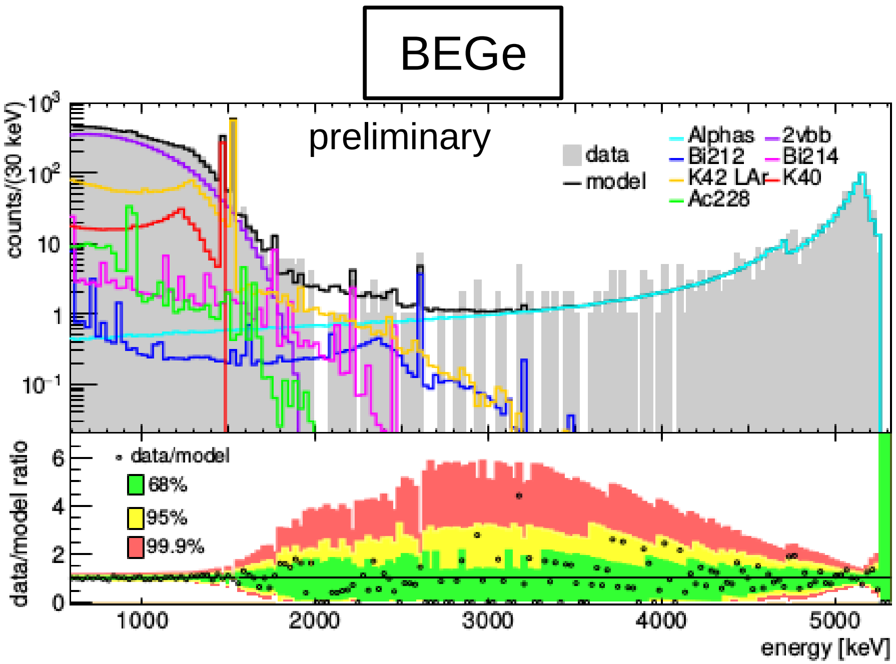


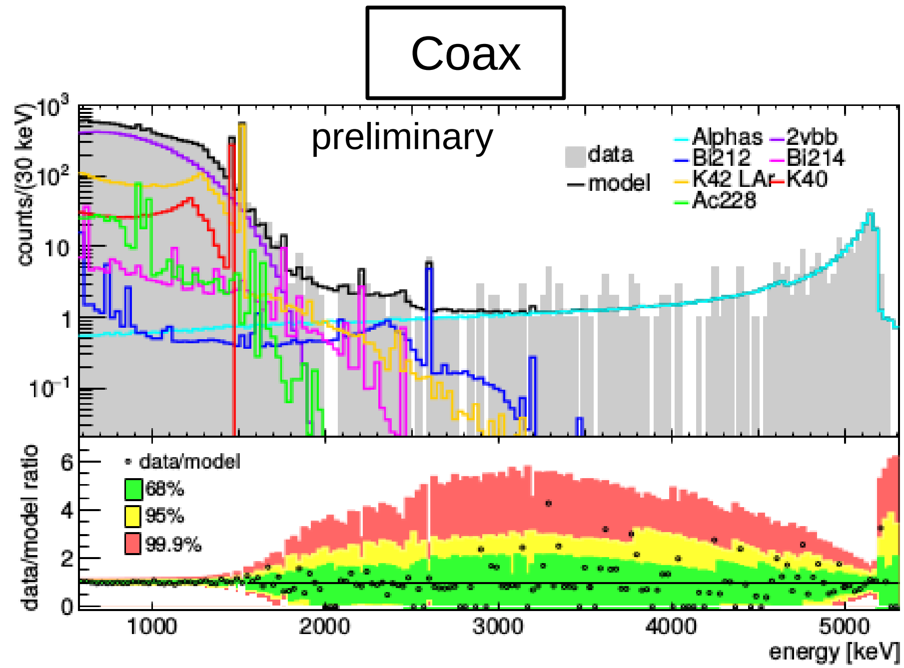
~2% dead time due to random coincidences with LAr veto

Phase II - First data release - Spectra



Phase II - First data release – Background model





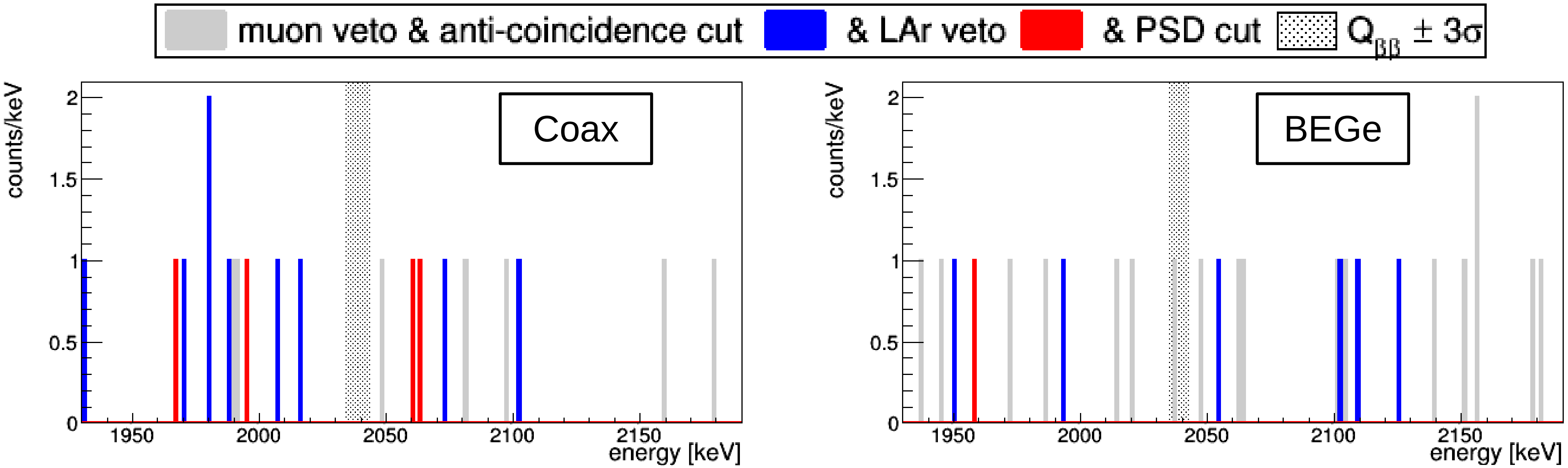
- pre LAr veto and PSD
- same isotopes as in Phase I
- main components:
  - ^{210}Po and ^{226}Ra on p^{+} contact
  - ^{42}K in Lar
  - ^{214}Bi, ^{208}Tl on detector assembly
- p-value of fit: 0.3 (BEGe), 0.6 (Coax)

- consequences for ROI
  - flat background
  - BI ~ 10^{-3} cts/(keV·kg·yr) after PSD+LAr
  - two closest gamma lines to ROI:

    2104 keV (^{208}Tl), 2119 keV (^{214}Bi)

    → cut out of 0νββ fit region

Phase II - First data release - ROI



		Coax	BEGe
cts expected from bkg	$Q_{\beta\beta}\pm 25$ keV	0.8	0.3
	1930-2190 keV	3.6	1.2
cts observed	$Q_{\beta\beta}\pm 25$ keV:	1	0
	1930-2190 keV:	4	1
background index	1930-2190 keV	$35^{+21}_{-15} \cdot 10^{-4}$	$7^{+11}_{-5} \cdot 10^{-4}$

[cts/(keV· kg· yr)]

Phase II - First data release - Results

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	BEGe	5.8	0.60 (2)	$7^{+11}_{-5} \cdot 10^{-4}$	3.0 (2)
Phase II	coaxial	5.0	0.51 (7)	$3.5^{+2.1}_{-1.5} \cdot 10^{-3}$	4.0 (2)

Preliminary!

- unbinned fit between 1930-2190 keV (removing two 10 keV γ-line windows)
- flat background + Gaussian signal
- no signal found (best fit: 0 counts)
- Frequentist: $T_{1/2} > 5.2 \cdot 10^{25}$ yr (90% C.L.) median sensitivity: $4.0 \cdot 10^{25}$ yr
  - profile likelihood
  - 2 sided test statistic and analysis procedure according to Eur. Phys. J. C 71 (2011) 1554
- Bayes: $T_{1/2} > 3.5 \cdot 10^{25}$ yr (90% C.I.) median sensitivity: $3.0 \cdot 10^{25}$ yr
  - flat prior

Summary

- first data release of GERDA Phase II successful
- excellent energy resolution
- background goal reached:
  - Coax: $3^{+2}_{-2} \cdot 10^{-3}$ cts/(keV·kg·yr)
  - BEGe: $7^{+11}_{-5} \cdot 10^{-4}$ cts/(keV·kg·yr)

  → lowest background in the field !
- sensitivity after 6 months:
  - Frequentist: $4.0 \cdot 10^{25}$ yr (90% C.L.)
  - Bayes: $3.0 \cdot 10^{25}$ yr (90% C.I.)
- no signal found → new limits:
  - Frequentist: $5.2 \cdot 10^{25}$ yr (90% C.L.) → $m_{\beta\beta} < 0.16\text{-}0.26$ eV
  - Bayes: $3.5 \cdot 10^{25}$ yr (90% C.I.)

Preliminary!
limits might change a little
after crosschecks of
PSD efficiencies

Thanks for your attention