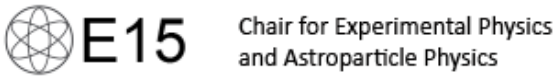
Status of the GERDA Experiment

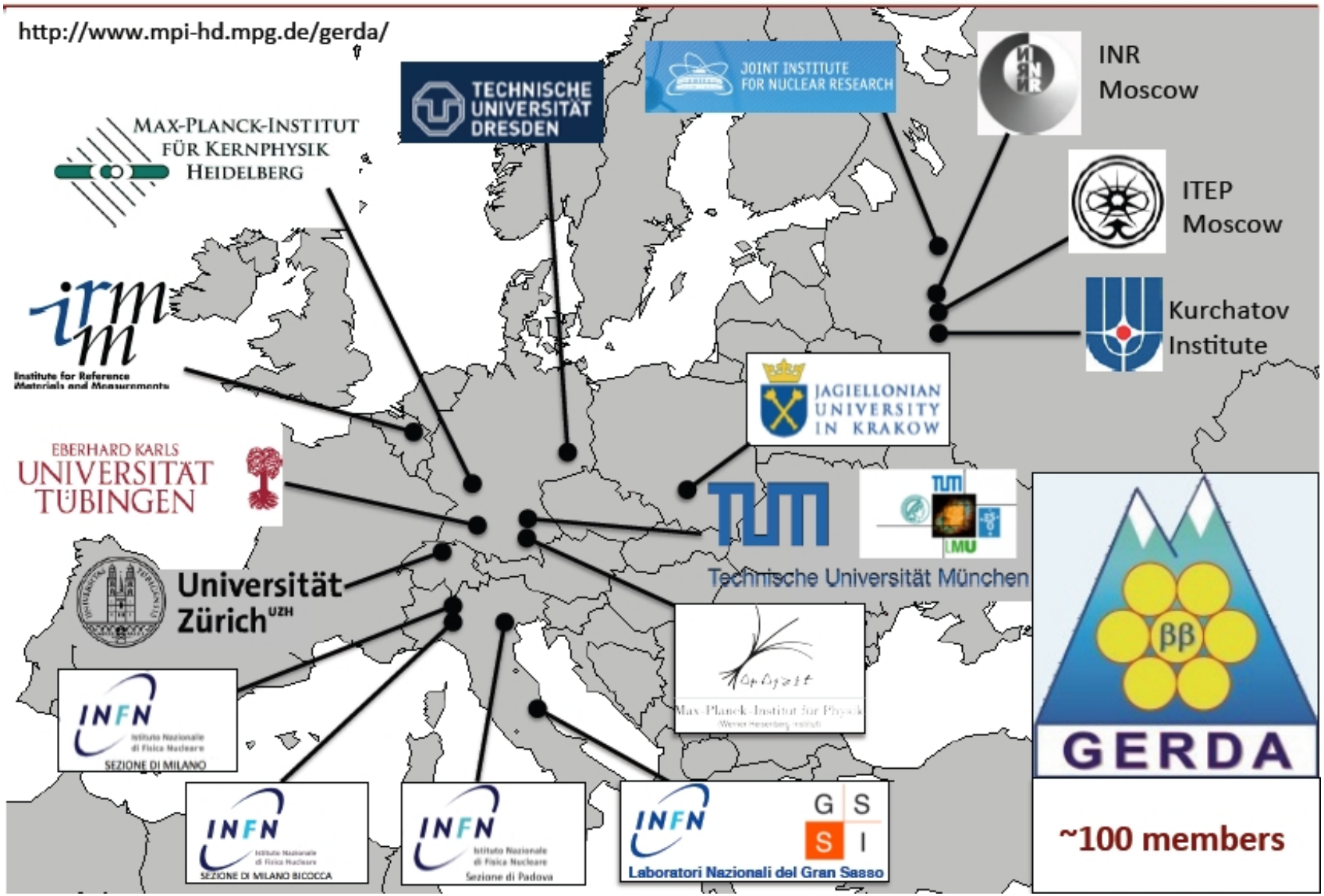
Andrea Lazzaro
on behalf of the GERDA collaboration



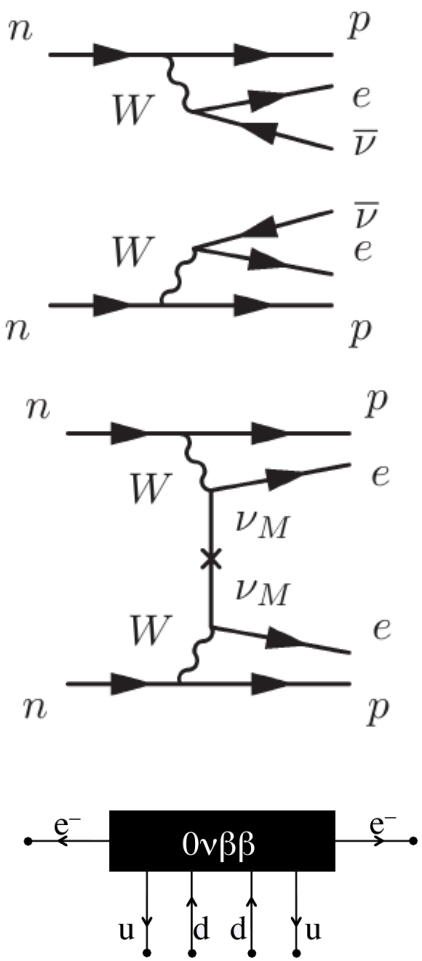
HQL VirginaTech, 23^{th} May 2016

1. GERDA
2. Phase I Results
3. Upgrade to Phase II
4. Phase II first data

GERDA Collaboration



Double Beta Decay



Neutrino emission ($2\nu\beta\beta$)

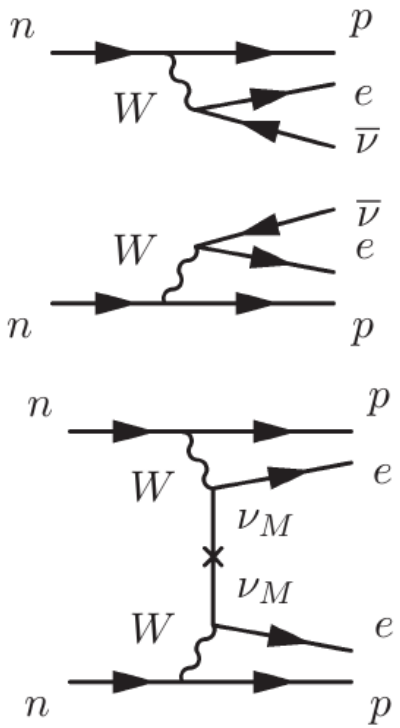
- $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\overline{\nu_e}$
- Observed in 11 nuclides
- $T_{1/2} \in (10^{19} - 10^{24})$
- Detection of $\Sigma E_{e^-} < Q_{\beta\beta}$

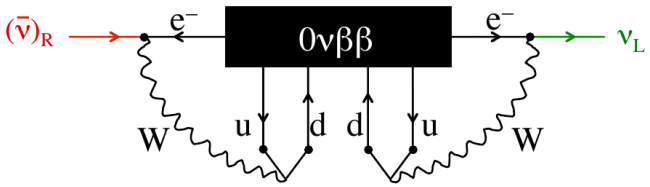
Neutrinoless ($0\nu\beta\beta$)

- $(A, Z) \rightarrow (A, Z+2) + 2e^-$
- Never observed so far
- Lepton number not conserved
- Requires a Majorana ν
- Detection of $\Sigma E_{e^-} = Q_{\beta\beta}$
- For light Majorana ν exchange:

$$1/T_{1/2} \propto \langle m_{\beta\beta} \rangle^2$$

Double Beta Decay





$(\bar{\nu})_R \rightarrow \nu_L$: A Majorana mass term

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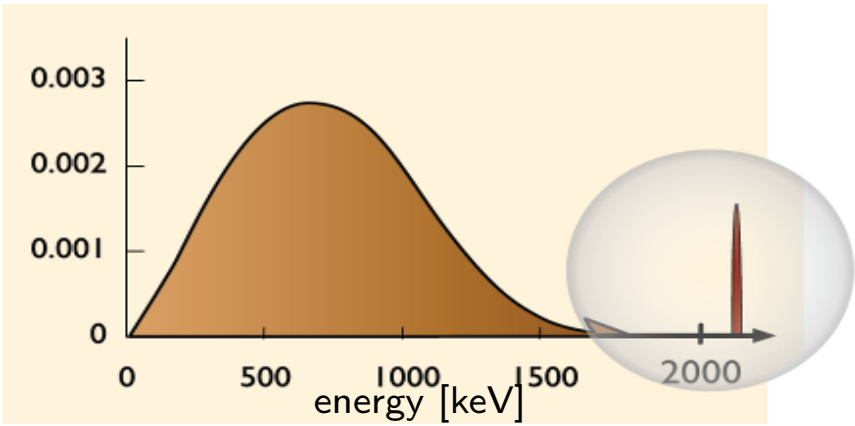
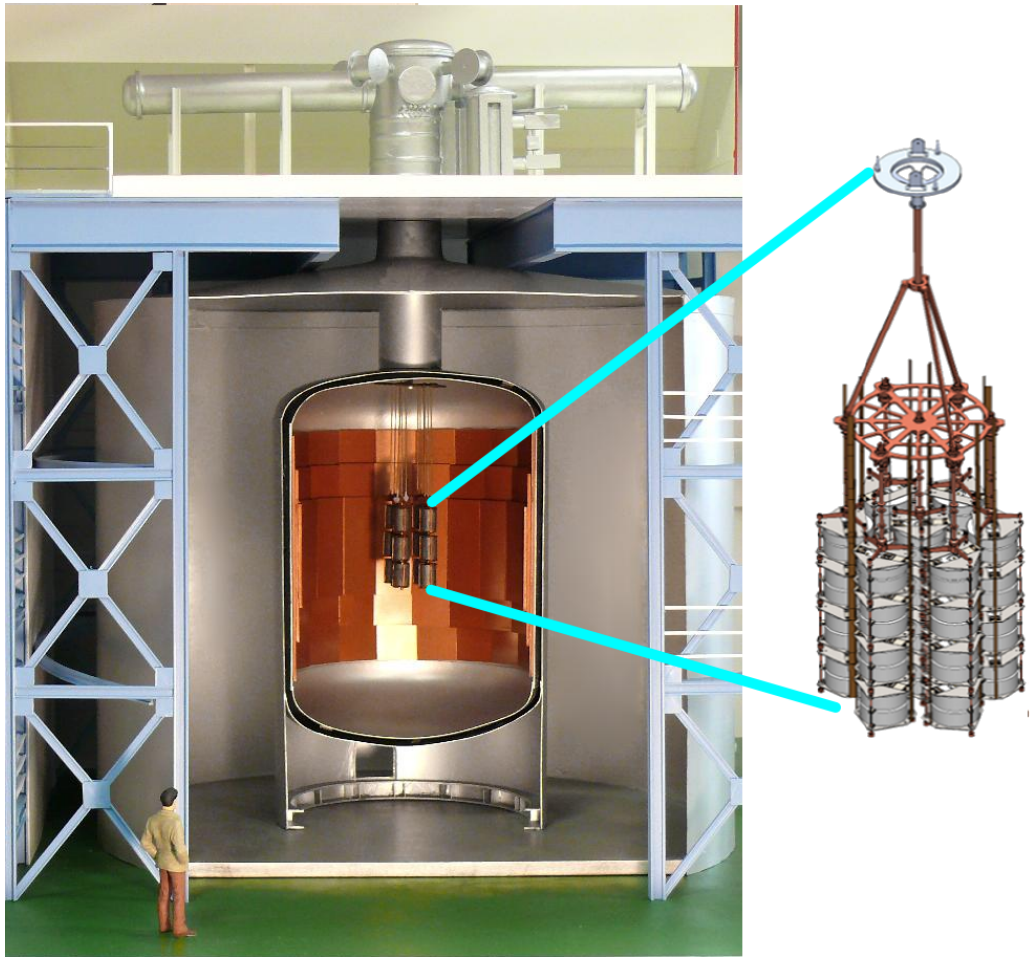
Experimental Search for Neutrinoless Double Beta in ^{76}Ge

- High purity semiconductor
- Enrichment: about 87% of ^{76}Ge
- $Q_{\beta\beta}$ value 2039 keV
- Resolution $\Delta E_{Q_{\beta\beta}} \sim 0.2\%$ (FWHM)
- High detection efficiency
- Modular
- Pulse shape discrimination of surface and multi-site events.



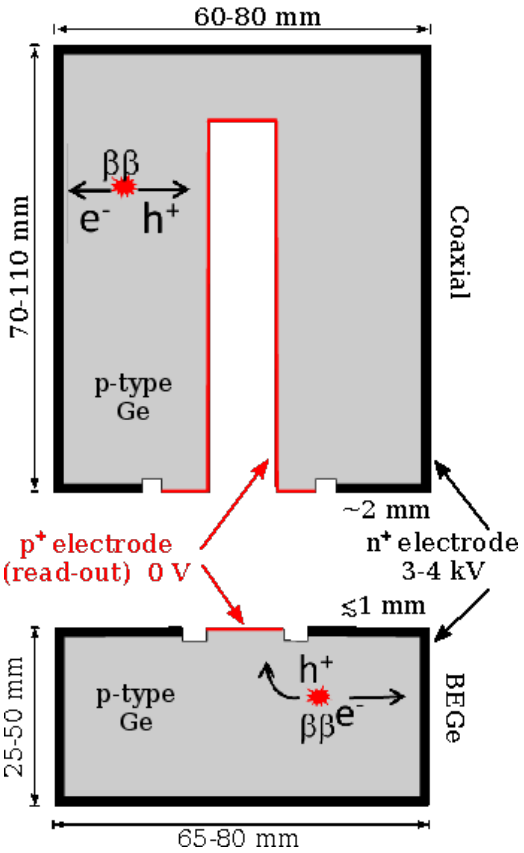
GERmanium Detector Array

- LNGS Laboratory
- Clean room:
  - Insertion system
  - Calibration system
- Water tank w/ Cherenkov veto
- Steel cryostat (64 m^3 LAr)
- Array

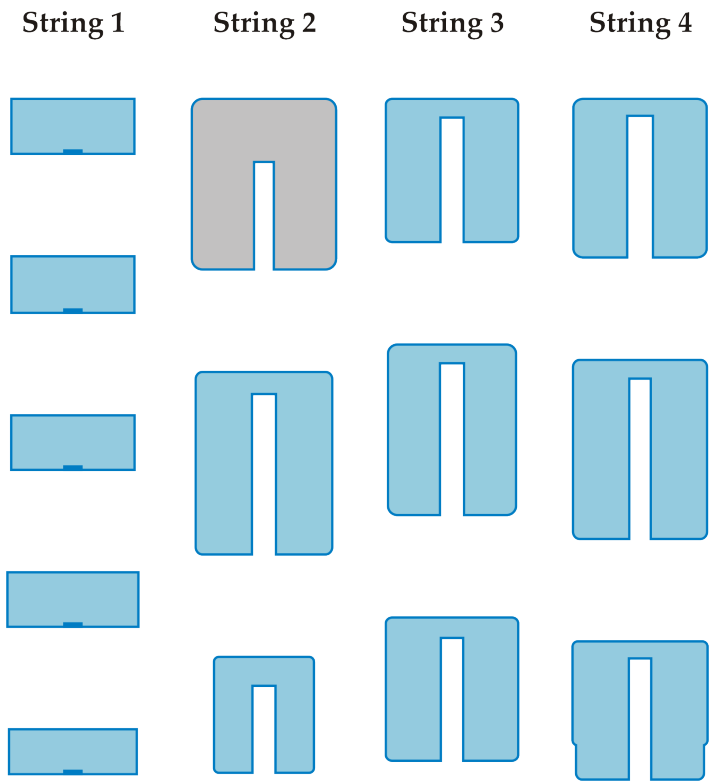


[Eur. Phys. J. C 73 (2013) 2330]

GERDA HPGe Detectors: Coaxial and BEGe



Phase I detectors layout



Coaxial mass:

17.7 + 3.0 kg

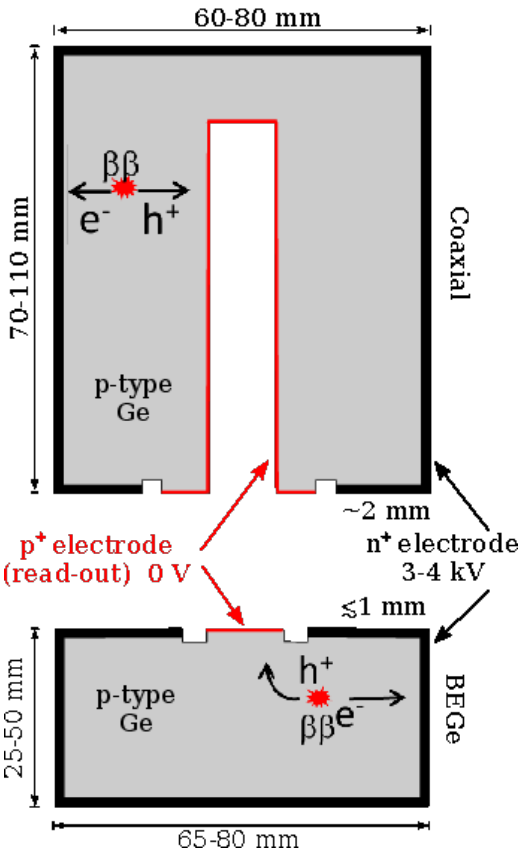
$\sim$ 2 kg/det

BEGe mass:

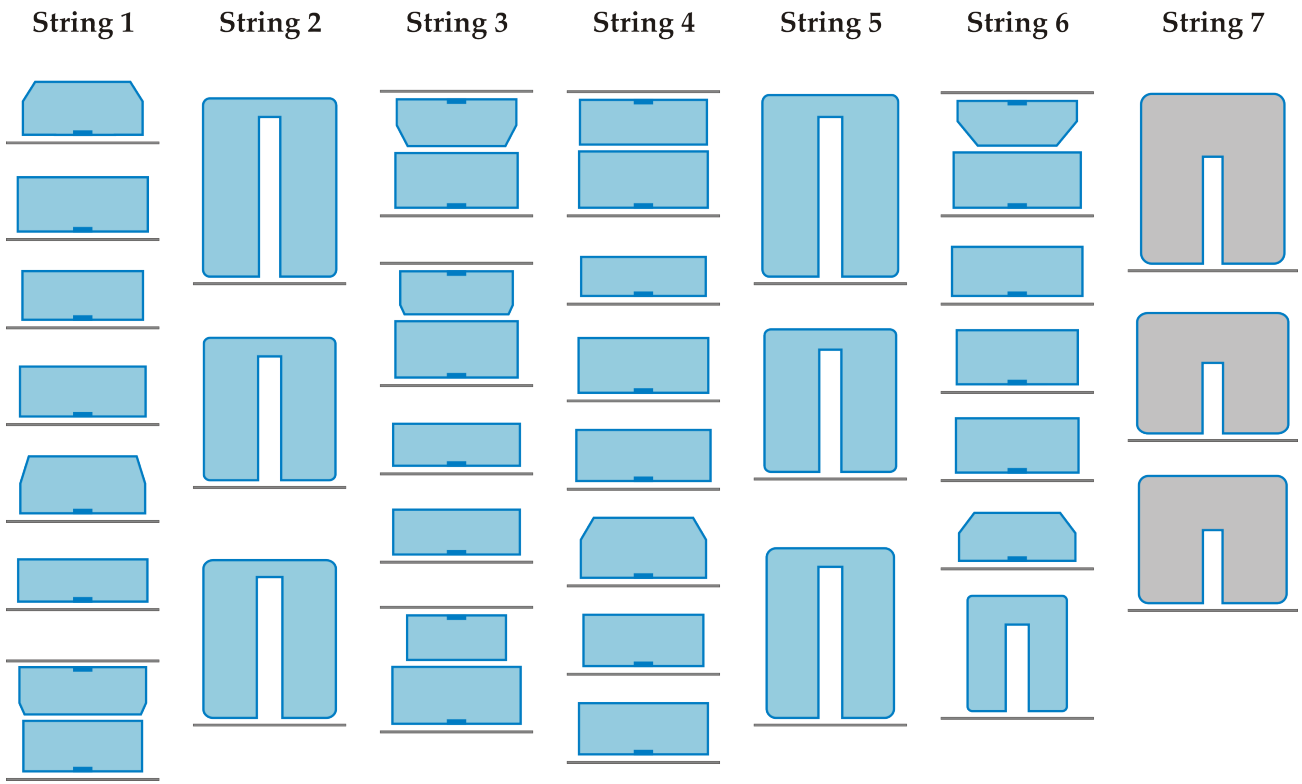
3.63 kg

$\sim$ 0.7 kg/det

GERDA HPGe Detectors: Coaxial and BEGe



Phase II detectors layout



Coaxial mass:

15.8 + 7.6 kg

$\sim$ 2 kg/det

BEGe mass:

20.0 kg

$\sim$ 0.7 kg/det

Phase I: Data Taking (2011-2013)

Nov2011 - May2013 (492 d)

5 BEGe det. from June 2012

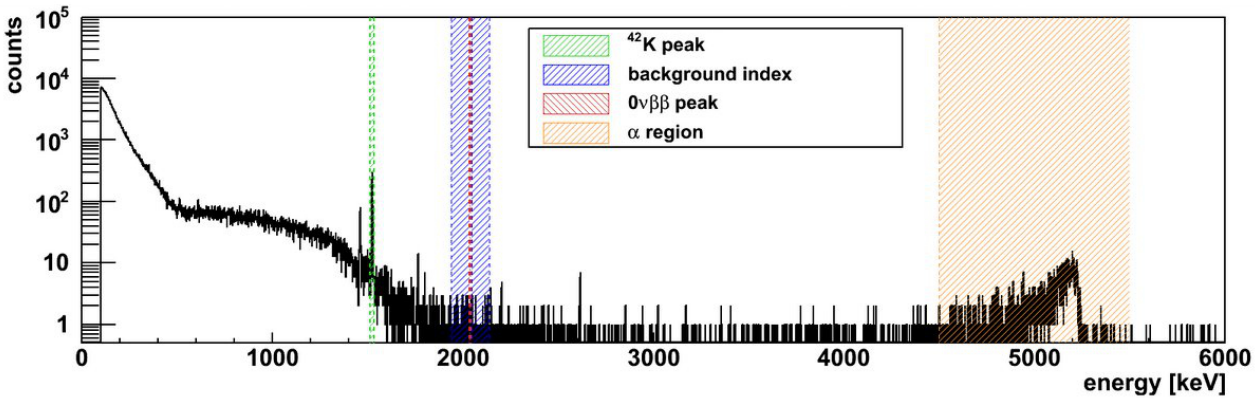
Energy resolution
FWHM at 2 MeV

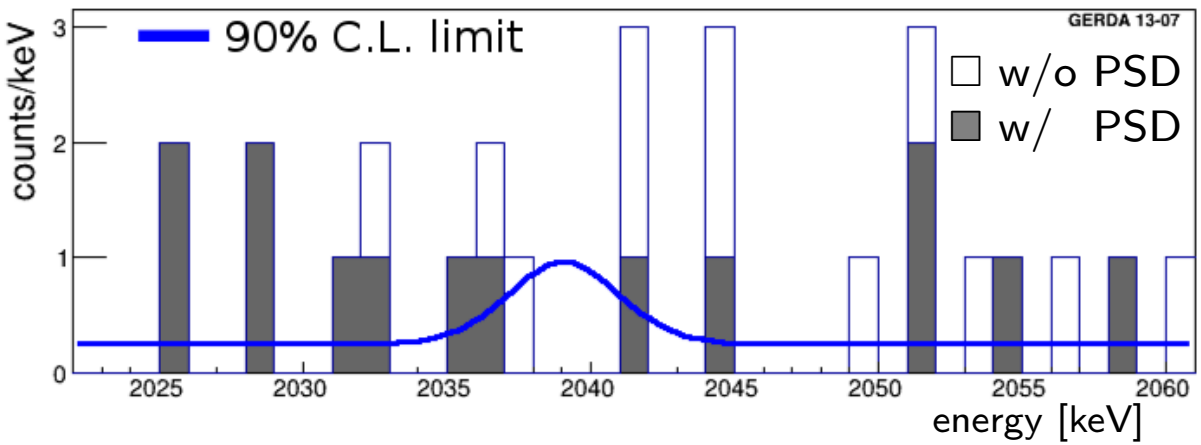
- BEGe: $\sim 3.2 \pm 0.2$ keV
- Coaxial: $\sim 4.8 \pm 0.2$ keV

Data Set	Exposure		B.I.*
Golden	17.9	kg · yr	11^{+2}_{-2}
Silver	1.3	kg · yr	30^{+11}_{-9}
BEGe	2.4	kg · yr	5^{+4}_{-3}

*in 230 keV interval [10^{-3} cts/(keV · kg · yr)]

Phase I: Current Limit for ^{76}Ge $0\nu\beta\beta$ Half-Life





- Blind analysis
- Exposure:
  $21.6\ \mathrm{kg \cdot yr}$
- Efficiency:
  $\epsilon = f_{76}\, f_{av}\, \varepsilon_{fep}\, \varepsilon_{psd}$
  - 62% for Coaxial
  - 66% for BEGe
- Sensitivity:
  $2.4 \cdot 10^{25}$ yr
- 2039 keV$\pm 1\sigma$
  0 counts
- Best fit:
  0 signal counts

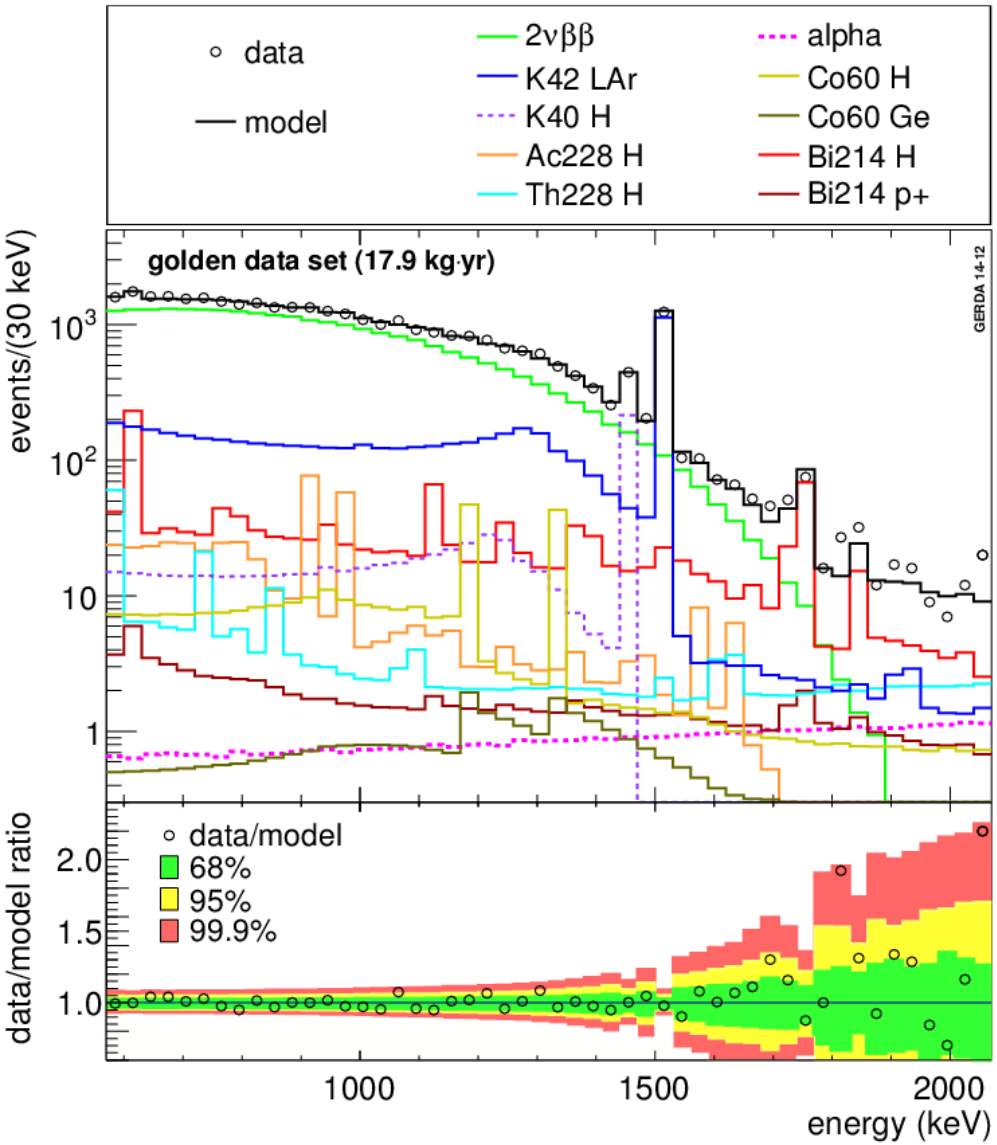
Limit:

$$T_{1/2}^{0\nu\beta\beta} > 2.1 \cdot 10^{25}\ \mathrm{yr} \qquad m_{\beta\beta} < 0.2 - 0.4\ \mathrm{eV}$$

(90% C.L.)

[P.R.L. 111 (2013) 122503]

Phase I: Measurement of ^{76}Ge $2\nu\beta\beta$ Half-Life

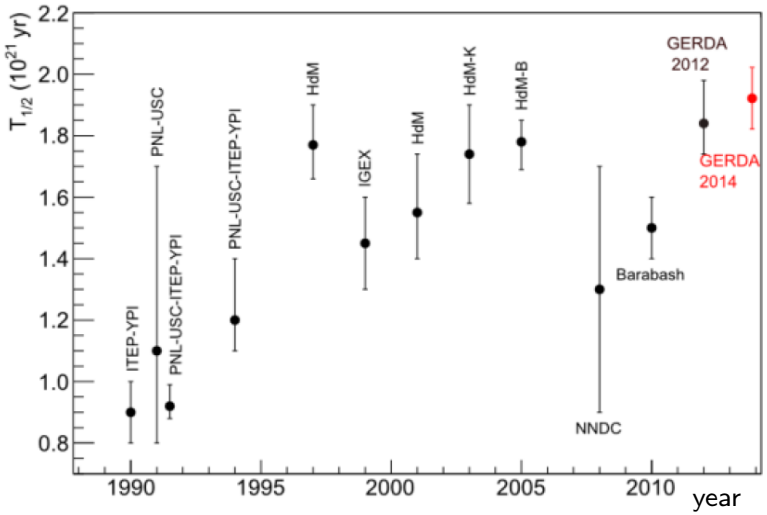


[Eur. Phys. J. C 75 (2015) 416]

- Golden data-set (17.9 kg · yr)
- Signal-to-background ratio:
  3:1 (570–2039) keV
  4:1 (600–1800) keV
- Uncertainties ^{76}Ge mass (4%)

$2\nu\beta\beta$ $T_{1/2}$:

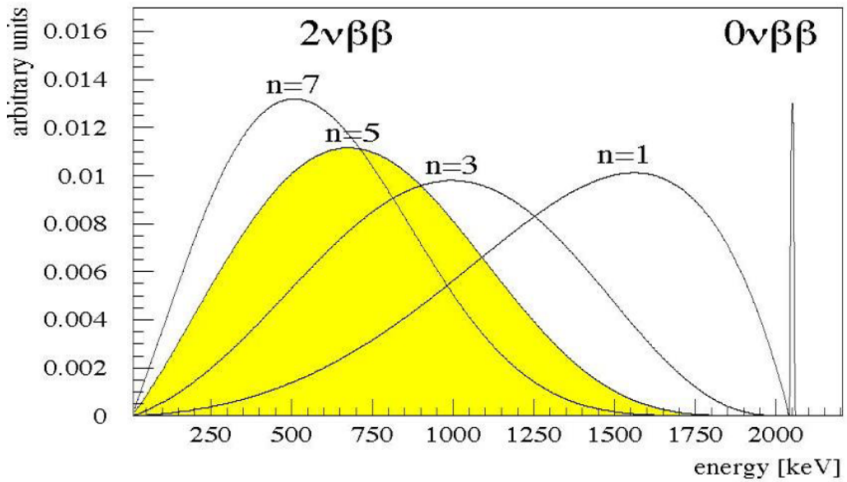
$$T_{1/2}^{2\nu\beta\beta} = 1.926 \cdot 10^{21}\,\text{yr}\ \left(^{+0.025}_{-0.022} \pm 0.092\right)$$

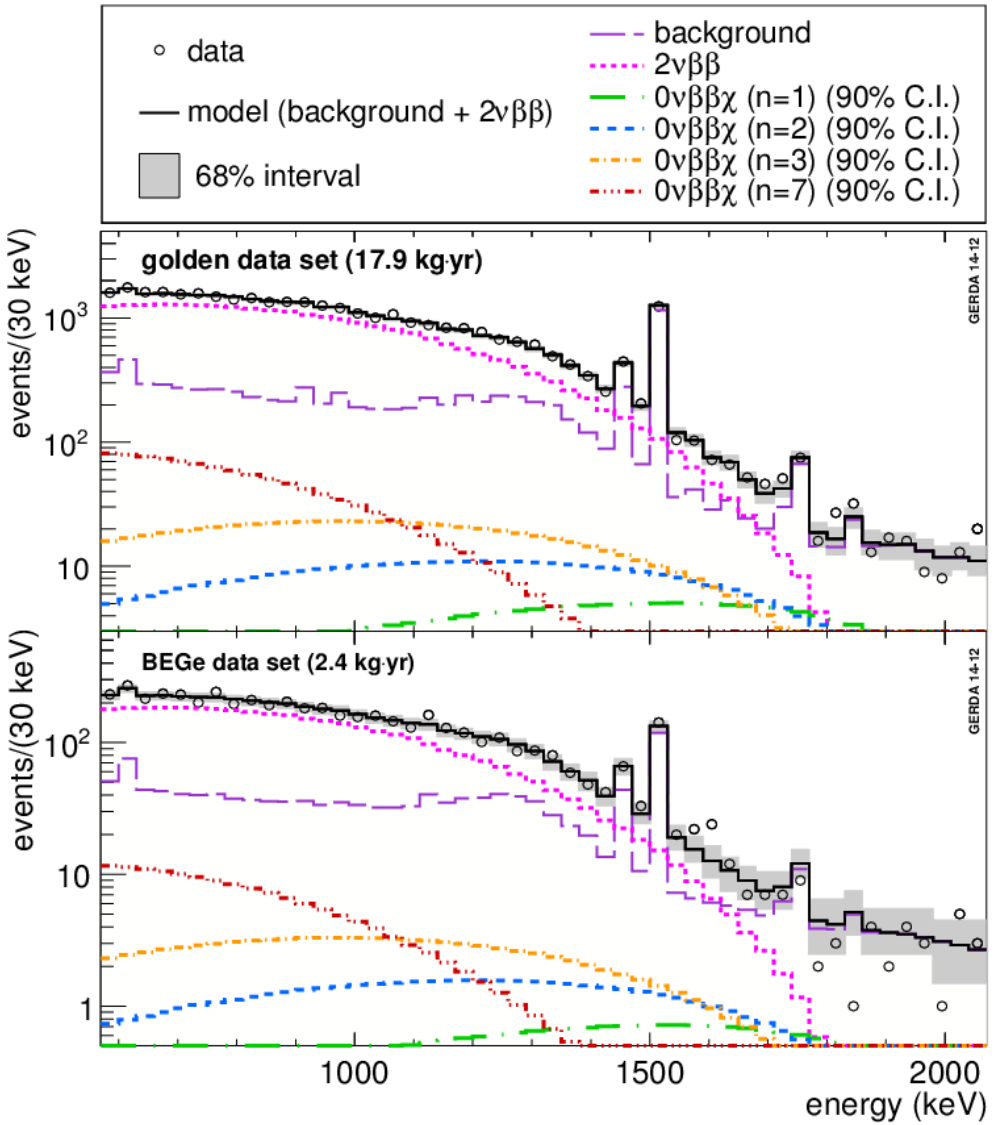


Phase I: Limits on Double Beta with Majoron(s) Emission

- Golden + BEGe data-set (20.3 kg · yr)
- $2\nu\beta\beta$ spectral index $n = 5$
- Test of models
- Limits improved ~ 6 times $n = 1, 3, 7$; first limit for $n = 2$

n	$T_{1/2}^{0\nu\chi}(90\%C.I.)$
1	$> 4.2 \cdot 10^{23}$ yr
2	$> 0.8 \cdot 10^{23}$ yr
3	$> 1.8 \cdot 10^{23}$ yr
7	$> 0.3 \cdot 10^{23}$ yr





[Eur. Phys. J. C 75 (2015) 416]

Phase I: Search for $2\nu\beta\beta$ to Excited States

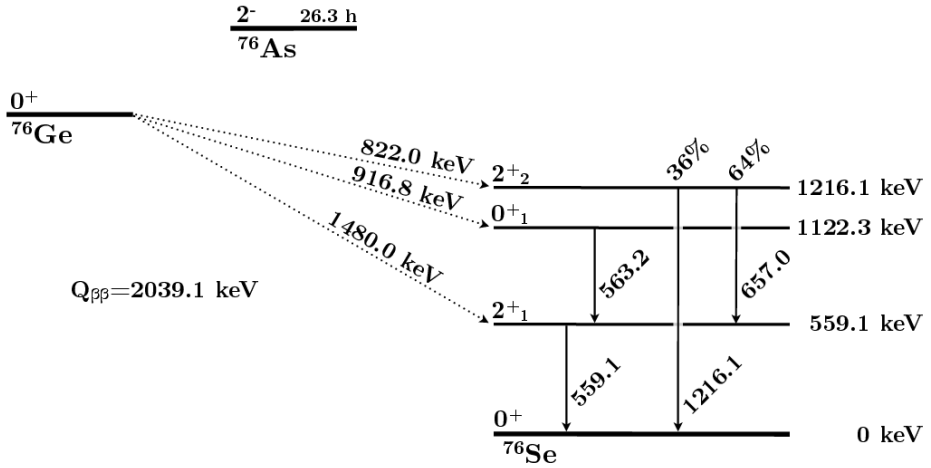
- Search for $2\nu\beta\beta$ and $0\nu\beta\beta$ to ^{76}Se excited states.
- Benchmark for NME.
- Coincidence signature

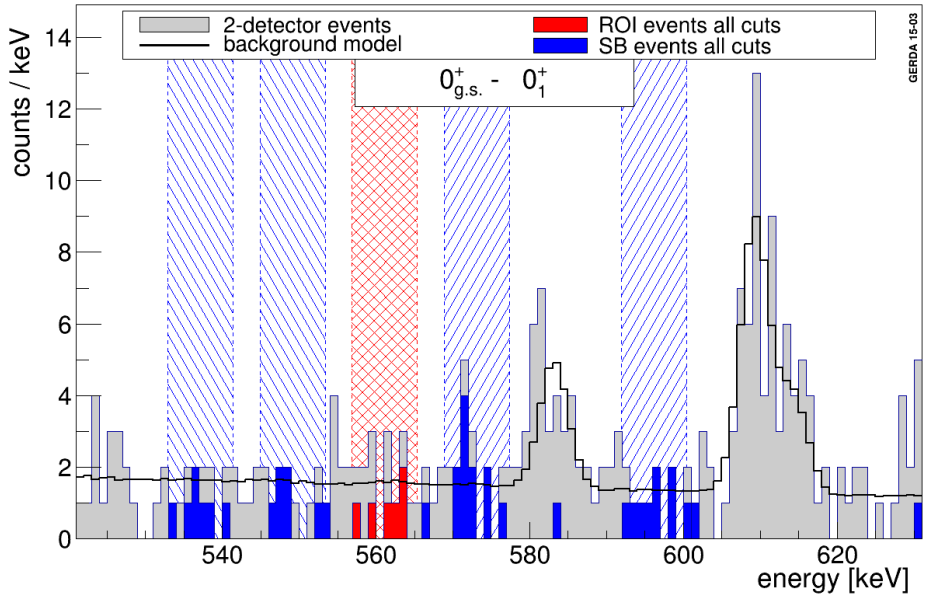
  Det.1: $\beta\beta$ energy
  Det.2: γ full energy

Decay Mode	$T_{1/2}$ [10^{23} yr]
$0^+_{g.s.} - 2^+_1$	> 1.6
$0^+_{g.s.} - 0^+_1$	> 3.7
$0^+_{g.s.} - 2^+_2$	> 2.3

90% C.L. limits

[J. Phys. G42 (2015) 115201]
Highlights of 2015





Phase II: How to increase one order of magnitude the sensitivity

Goals:

Sensitivity above $1 \cdot 10^{26}$ yr

Exposure ~ 100 kg $\cdot$ yr

Background index
10^{-3} cts/(keV $\cdot$ kg $\cdot$ yr)

What's new?

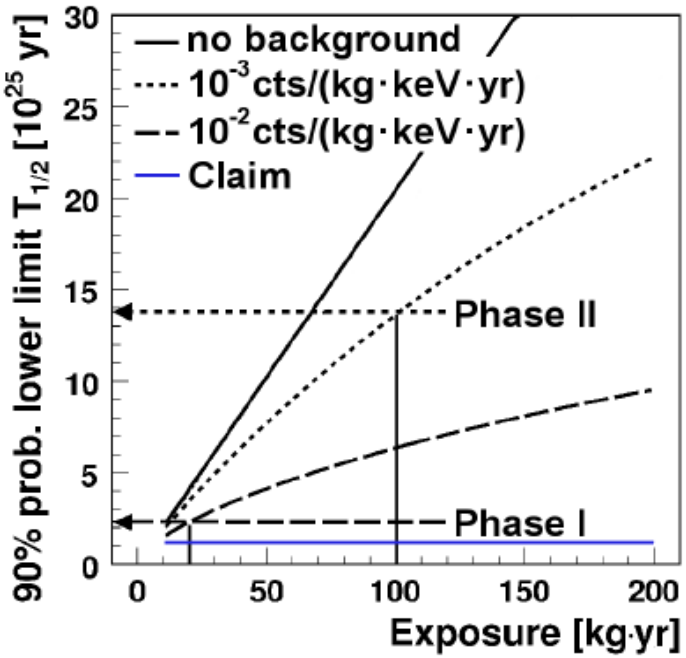
30 custom BEGe detectors ($\sim$ 20 kg)

Background veto

if $b \cdot \delta e \cdot m \cdot t \gg 1$

$$S(t_{1/2}^{0\nu}) \propto \epsilon \cdot a \cdot \sqrt{\frac{m \cdot t}{b \cdot \delta e}}$$

ϵ	efficiency	m	target mass
a	enrichment	b	background index
δe	E. resolution		



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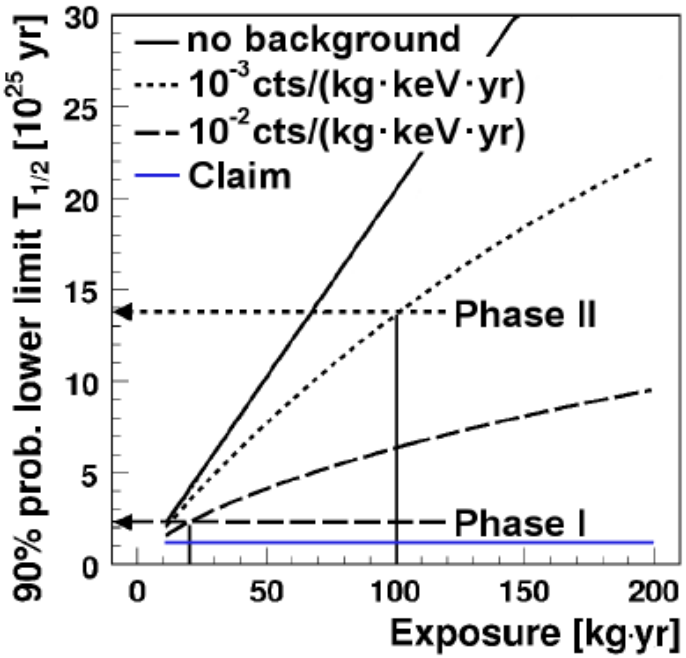
Background veto

if $b \cdot \delta e \cdot m \cdot t = 0$

$$S(t_{1/2}^{0\nu}) \propto \epsilon \cdot a \cdot m \cdot t$$

ϵ	efficiency	m	target mass
a	enrichment	b	background index
δe	E. resolution		



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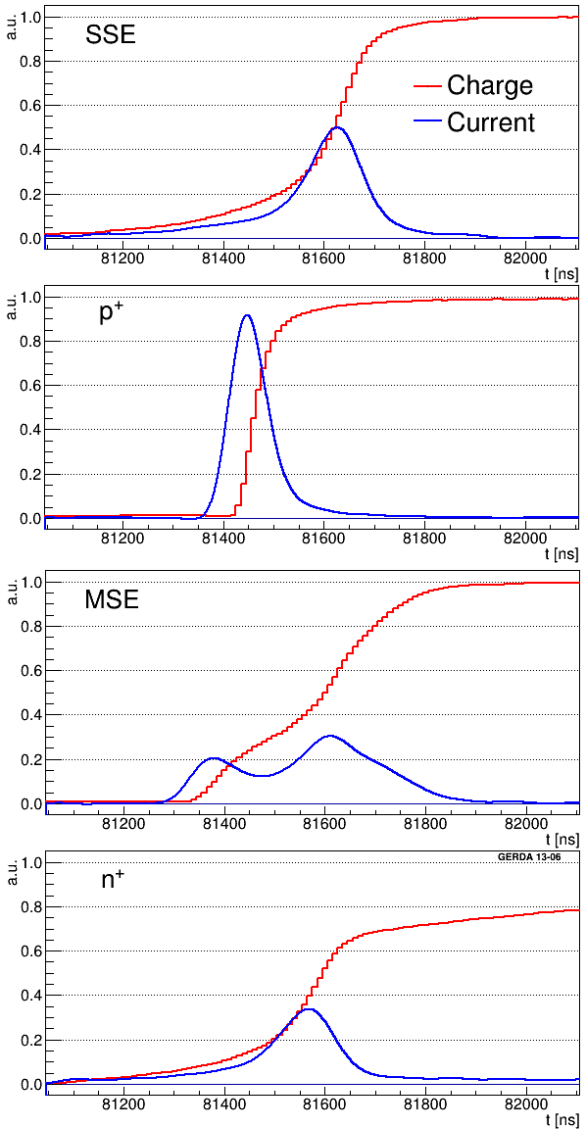
- energy resolution
  ~ 3 keV FWHM @ 2 MeV
- pulse shape discrimination
  of bulk single site events against
  surface events (α&β) and MSE

Background veto



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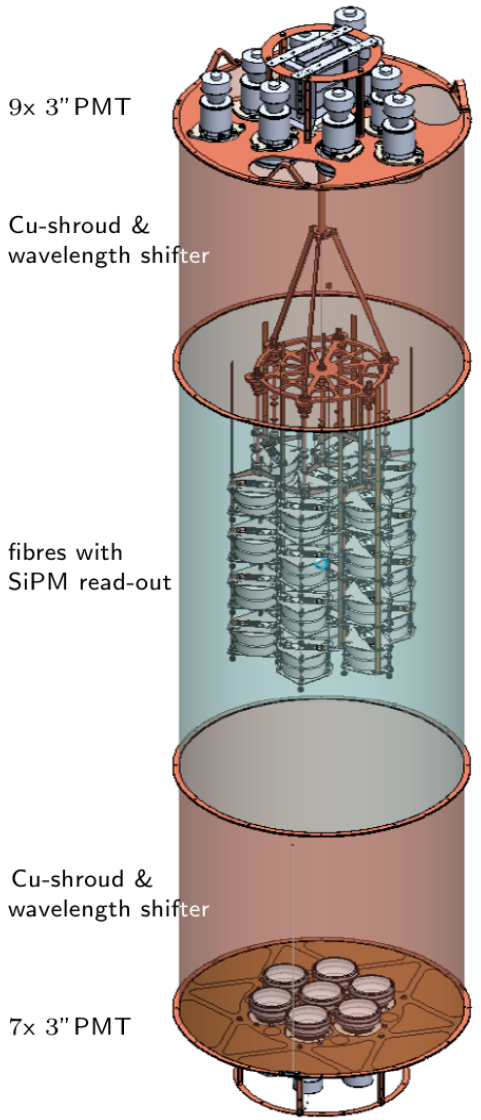
What's new?

30 custom BEGe detectors ($\sim$ 20 kg)

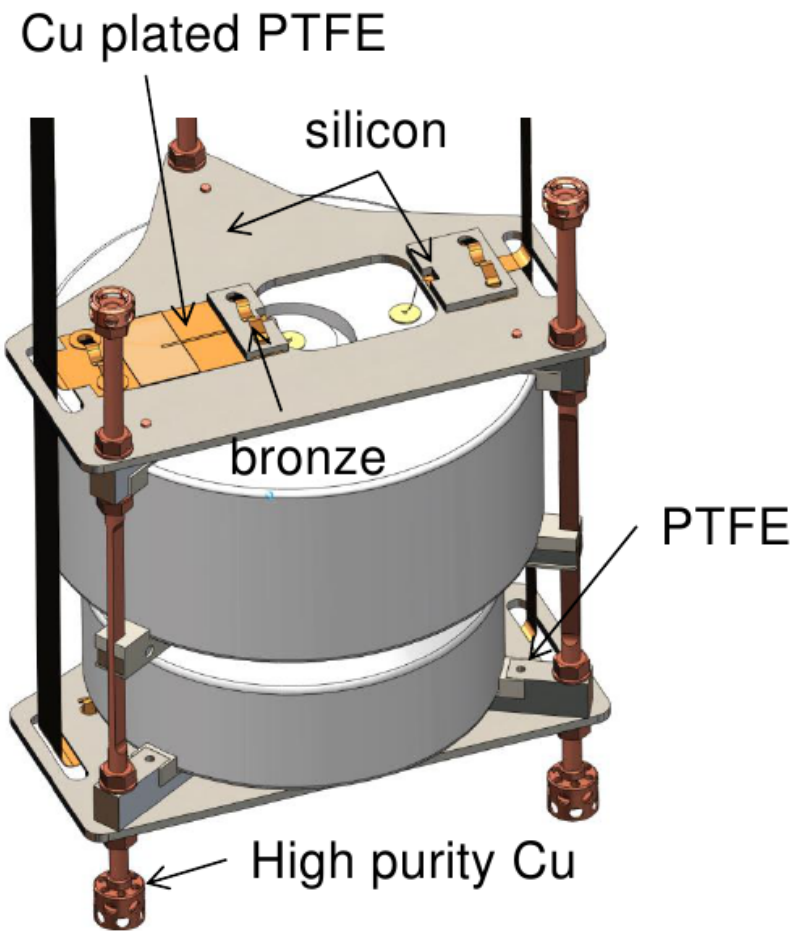
- energy resolution
  $\sim$ 3 keV FWHM @ 2 MeV
- pulse shape discrimination
  of bulk single site events against
  surface events (α&β) and MSE

Background veto

- LAr scintillating read–out
- better anti-coincidence



The Phase II Array



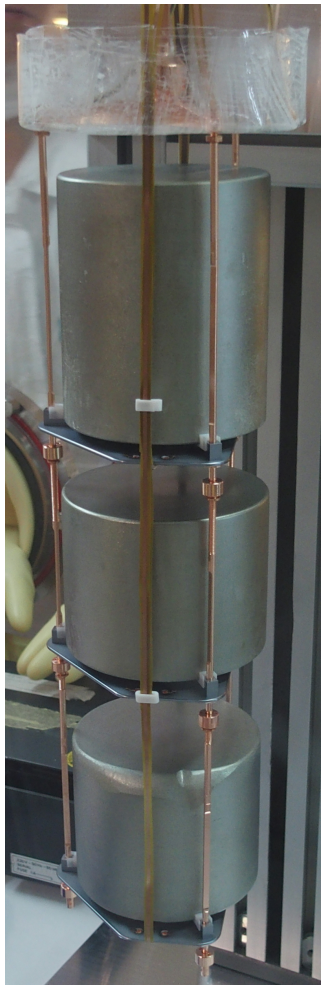
Holder:

Bonded contacts

Low mass structure

Cu & mono-crystalline Si plates

The Phase II Array



Holder:

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Low mass structure

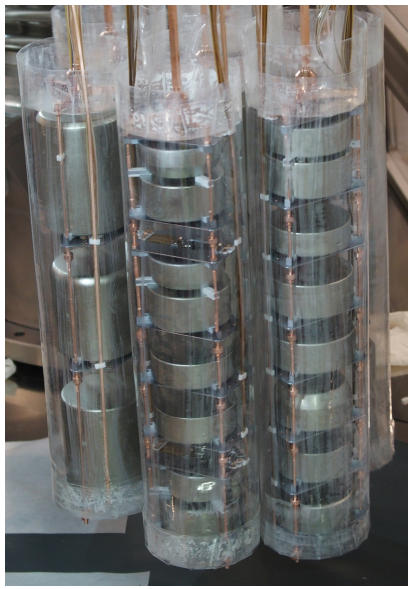
Cu & mono-crystalline Si plates

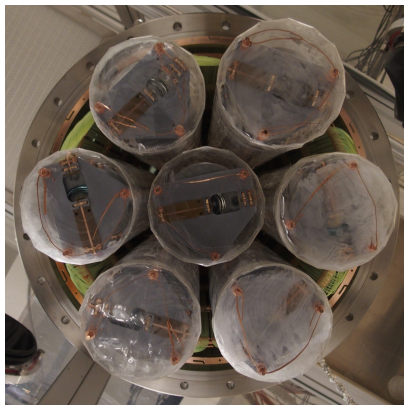
String:

Up to 8 BEGes or 3 coaxials

Nylon mini-shroud
to avoid collection of ^{42}K

The Phase II Array





Holder:

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Low mass structure

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String:

Up to 8 BEGes or 3 coaxials

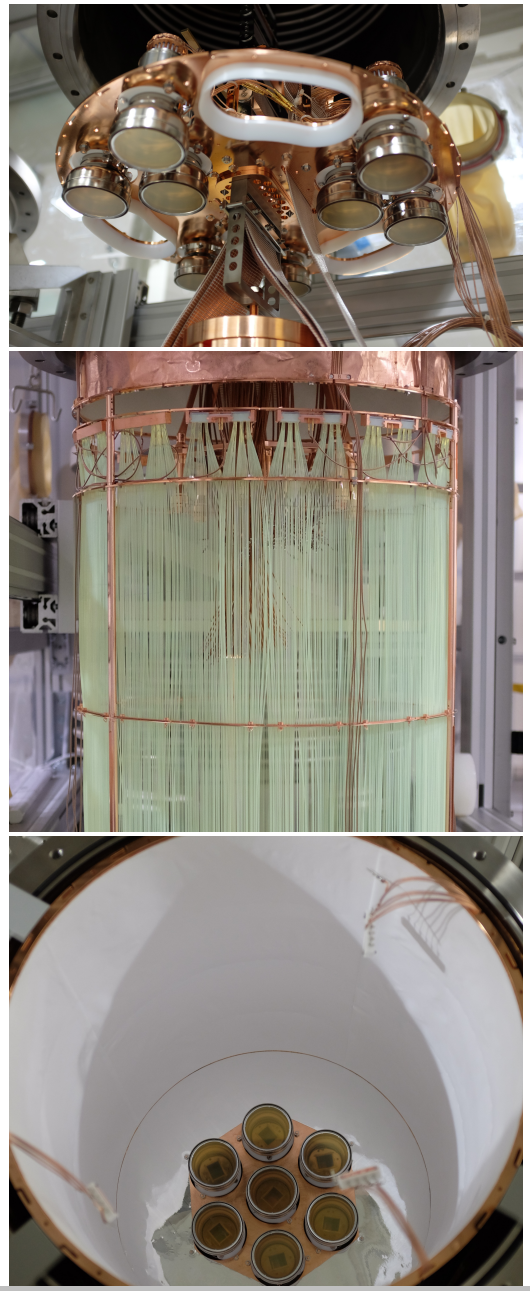
Nylon mini-shroud
to avoid collection of ^{42}K

Array:

7 strings of HPGe

LAr veto: PMTs and fiber curtain

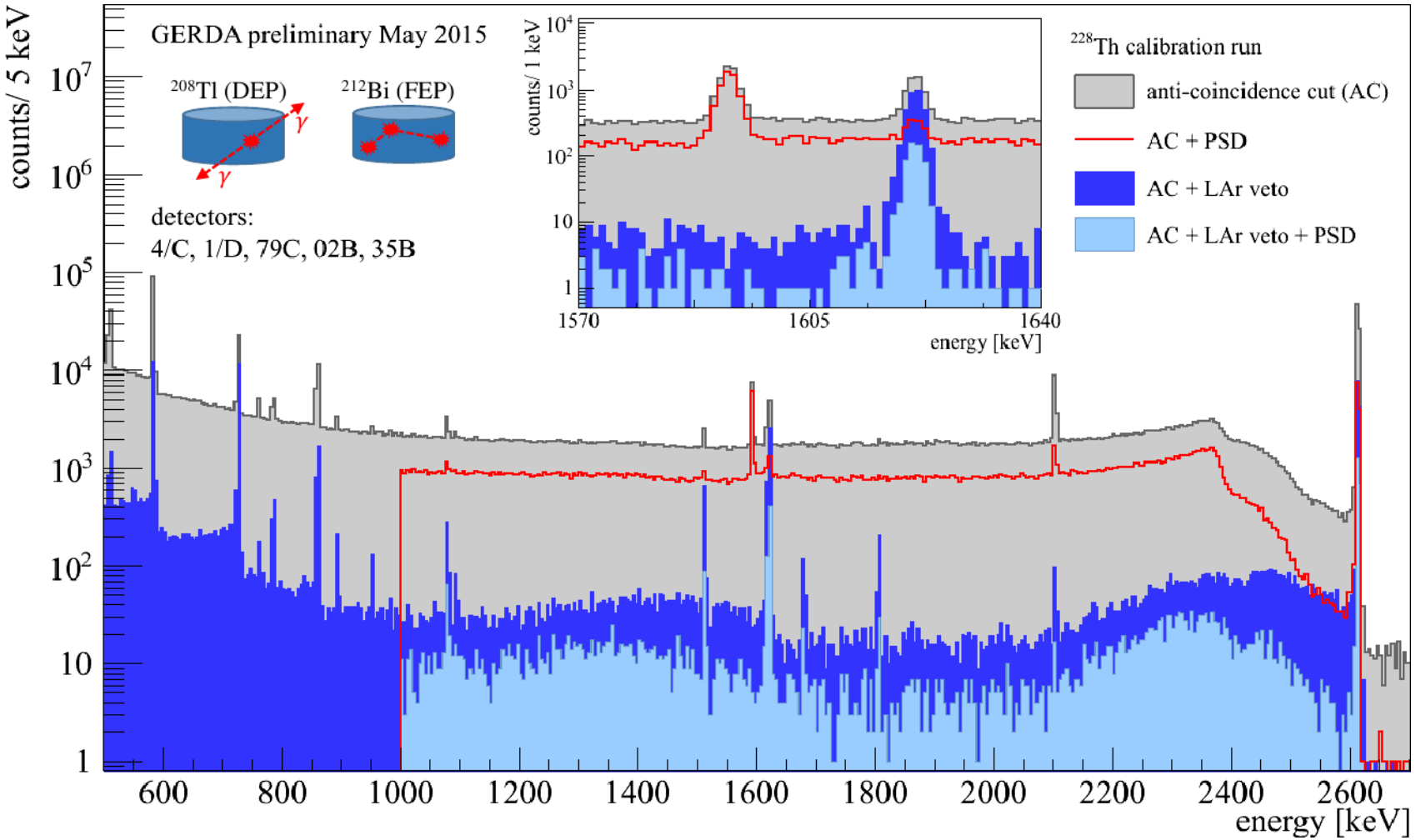
Liquid Argon Veto



- Ionization in LAr
- UV Scintillation
- Shift to visible light

  Wavelength-shifter coating:
  - mini-shroud
  - copper shroud
  - optical fiber
- Light Detection
  - top plate 9 PMT's
  - SiPM's coupled to each fiber
  - bottom plate 7 PMT's

PSD and LAr Veto synergy on suppression for Th



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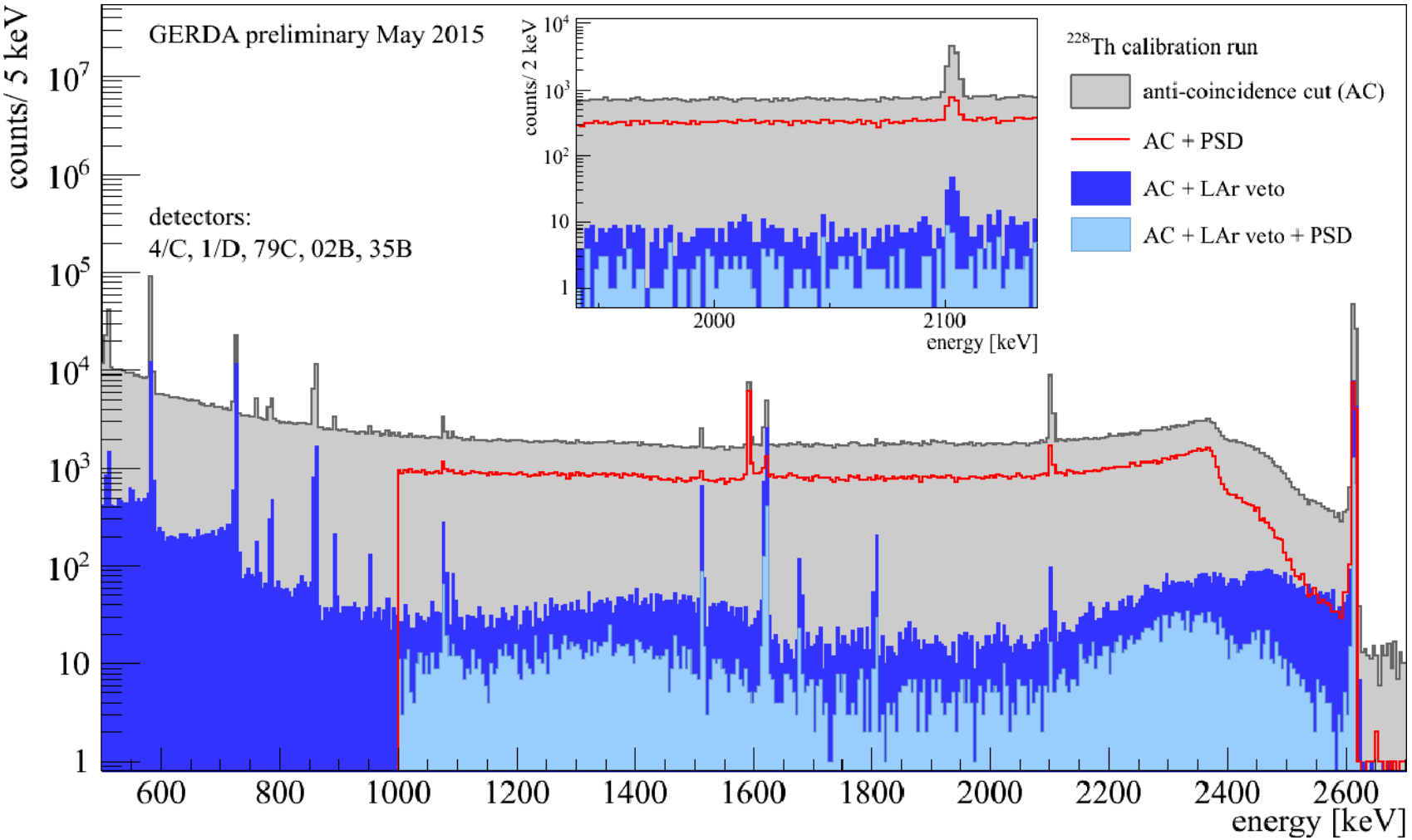


Phase II taking data since Dec. 2015

Status:

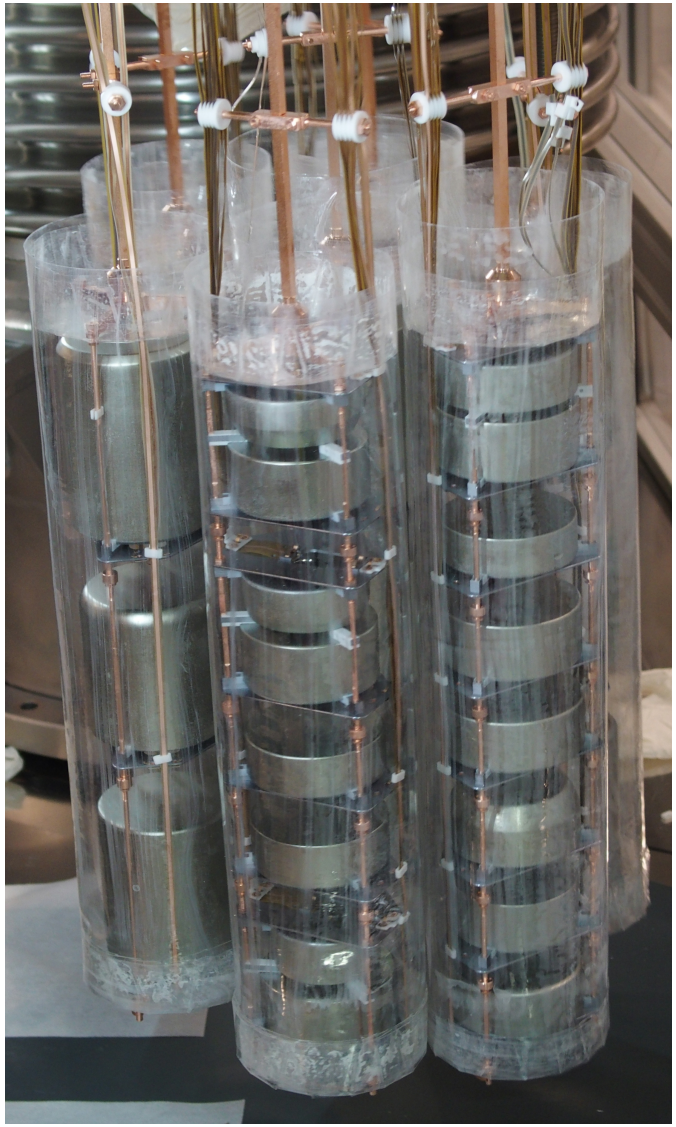
- December 20^{th}, Phase II start taking data
- 7 strings – 40 detectors
- exposure by 11^{th} Feb 2016: ~ 2.6 kg $\cdot$ yr

Energy Resolution:

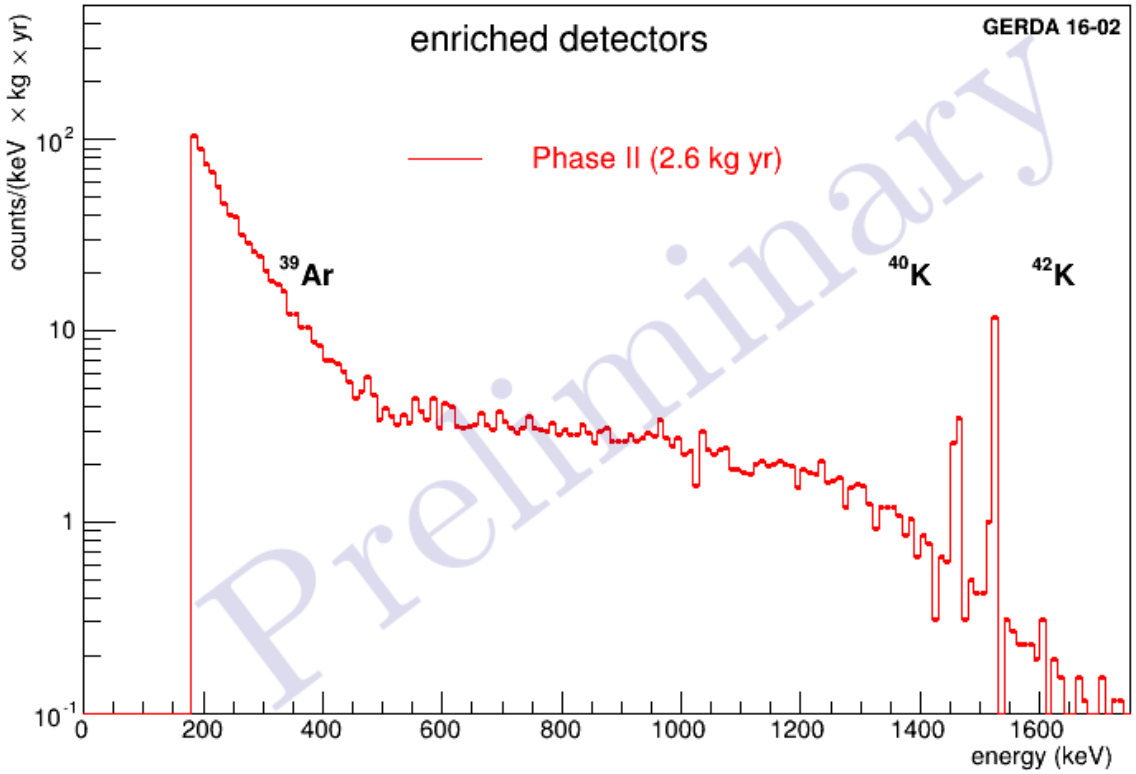
(FWHM at 2.6 MeV)

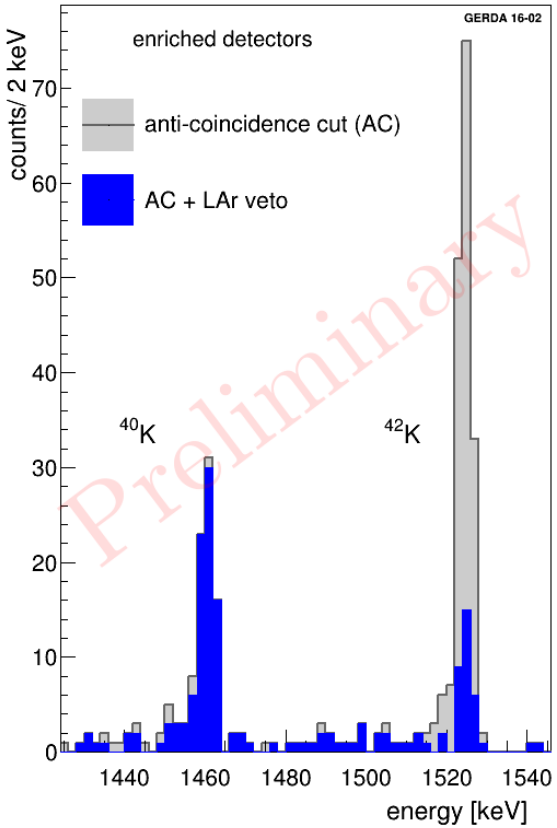
- BEGe: ~ 3.4 keV
- Coaxial: ~ 4.0 keV

30 enr. BEGe det. (20.0 kg)
7 enr. Coaxial det. (15.8 kg)
3 nat. Coaxial det. (7.6 kg)



First Background Spectrum shows no surprises



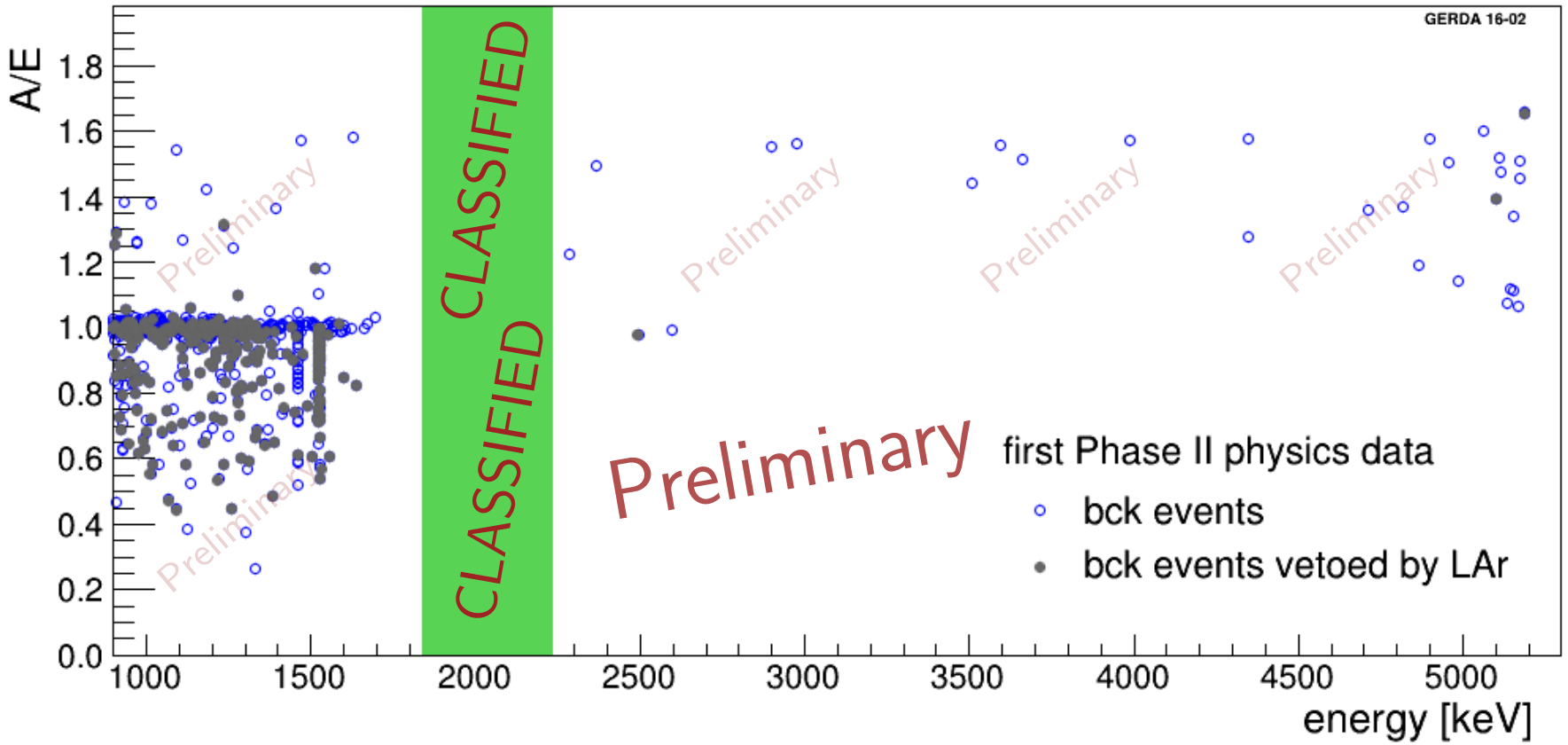


survival probability:

^{40}K $(98 \pm 4)\%$

^{42}K $(18 \pm 4)\%$

BEGe's Pulse Shape Analysis



Summary

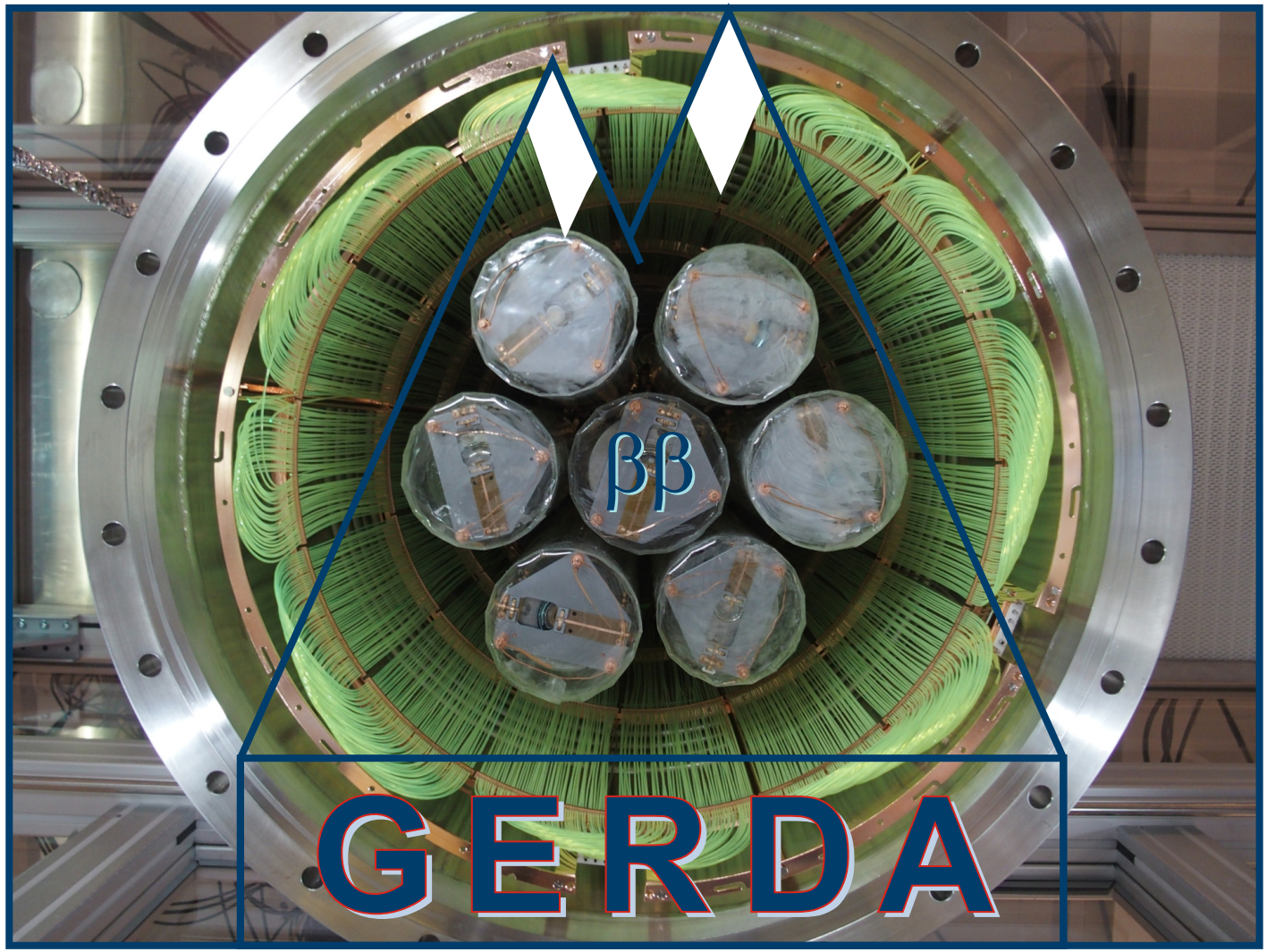
Phase I

Further analysis of data from the first phase of GERDA:

- $2\nu\beta\beta$ half-life
- $0\nu\beta\beta\chi$, $0\nu\beta\beta\chi\chi$ limits
- $2\nu\beta\beta$ to excited states

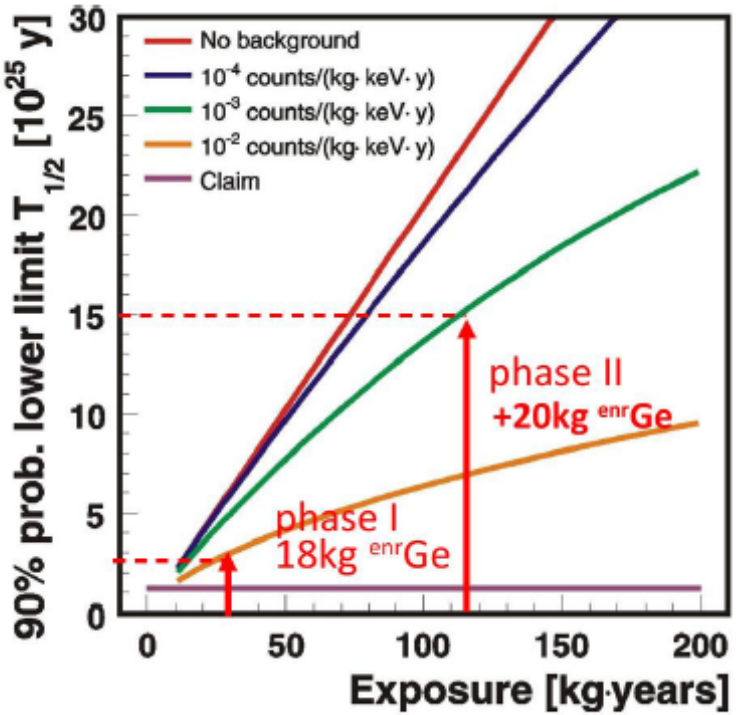
Phase II Status & Performance

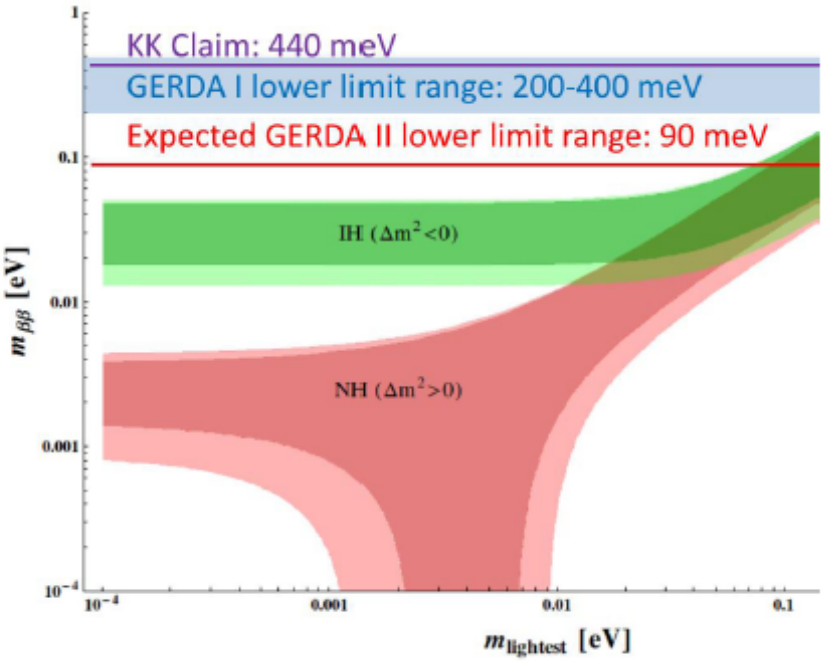
- start data taking December 20, 2015
- 40 HPGe detectors are currently operated in GERDA
- $\sim$ 35 kg of enriched ^{76}Ge ($\sim$ 87%)
- LAr veto system is working
- about 2.6 kg $\cdot$ yr of exposure until Feb2016
- no unforeseen sources of background have been observed



Thank you!

GERDA Sensitivity

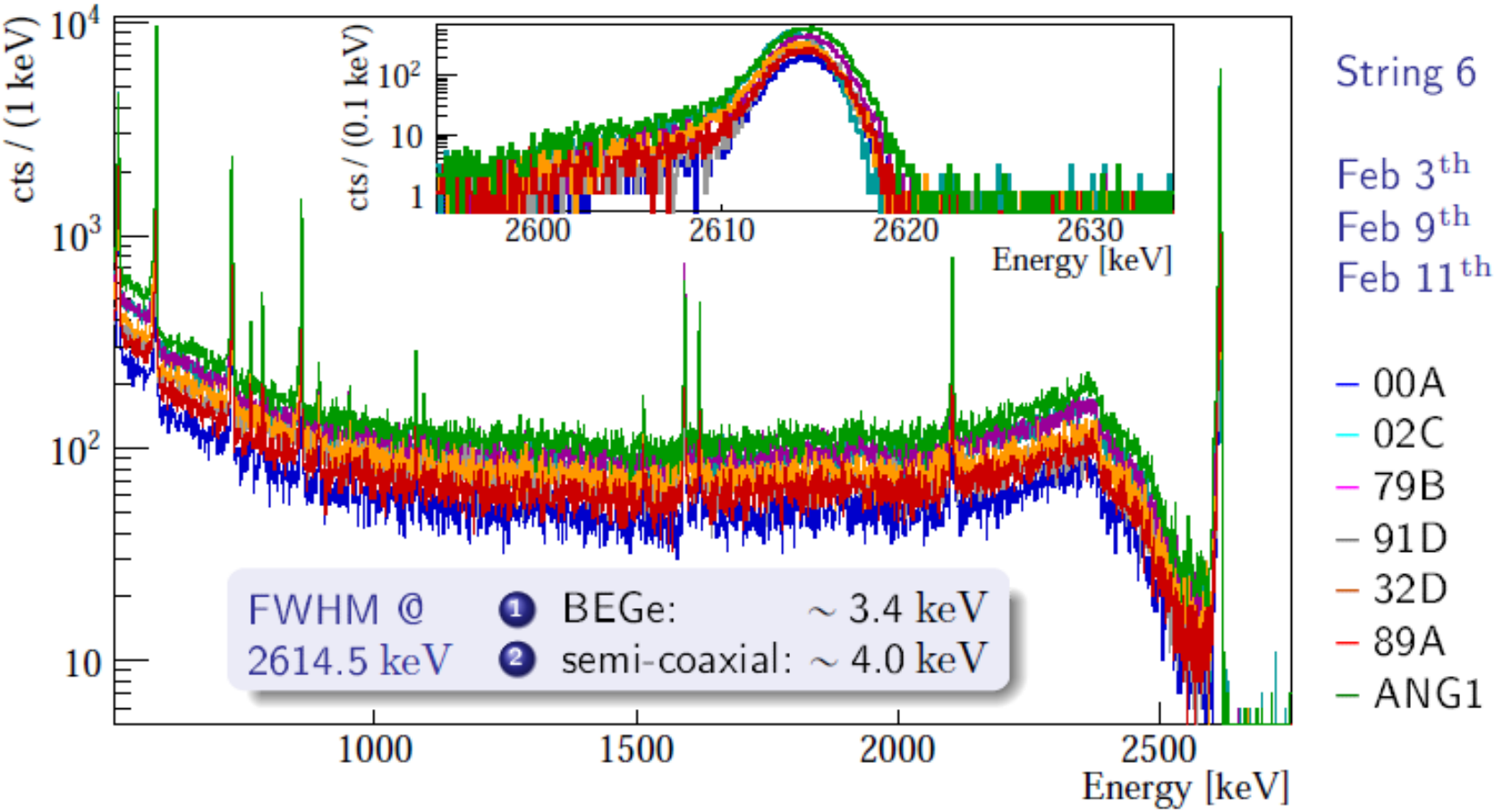




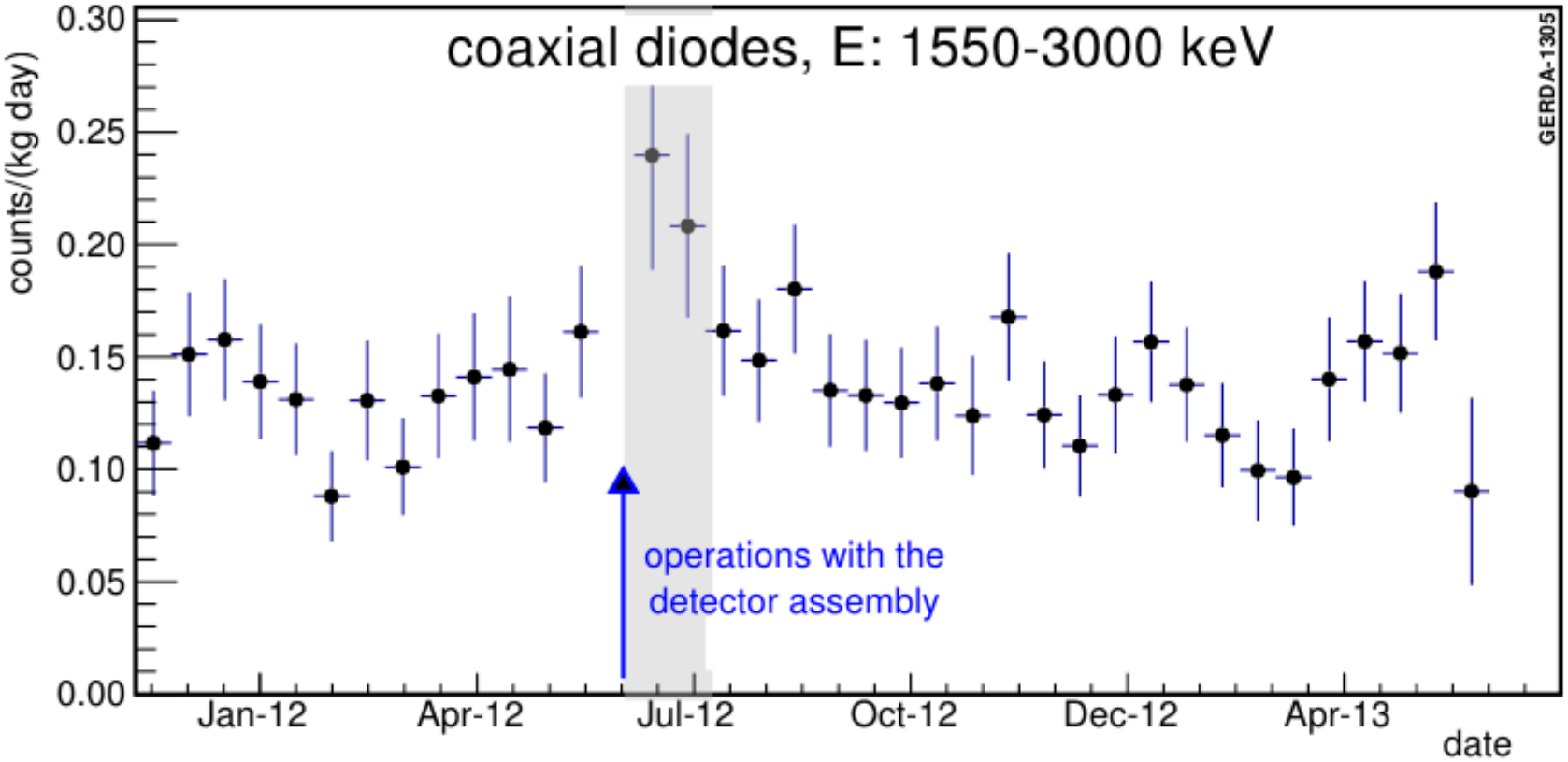
DellOro, Marcocci, Vissani,
hep-ph/1404.2616v1

reach $T^{0\nu}_{1/2} \sim 1.5 \cdot 10^{26}$ yr (exposure 120 kg·yr) $\Rightarrow m_{\beta\beta} \lesssim 90 - 150$ meV

Commissioning Run - Energy Calibration



Phase I count-rate: Silver and Golden data-set.



$0\nu\beta\beta$ half-life limits

$$T_{1/2}^{0\nu\beta\beta} = \ln 2 \frac{N_A}{m_{enr}} \frac{M \cdot t}{N_{0\nu}} \cdot \varepsilon_{76} \cdot \epsilon_{av} \cdot \epsilon_{fep} \cdot \epsilon_{psd}$$

Data Set	$M \cdot t[kg \cdot y]$	ε_{76}	ϵ_{av}	ϵ_{fep}	ϵ_{psd}
Golden	17.9	0.86	0.87	0.92	0.90
Silver	1.3	0.86	0.87	0.92	0.90
BEGe	2.4	0.88	0.92	0.90	0.92

- 3 fit in 1930-2190 keV
- constant background levels
- gauss peak for $0\nu\beta\beta$
  $\mu = 2039$
  $\sigma_{coax} = 2.0$ $\sigma_{BEGe} = 1.4$
- 4 free parameter
  (bkg levels & $T^{0\nu}$)

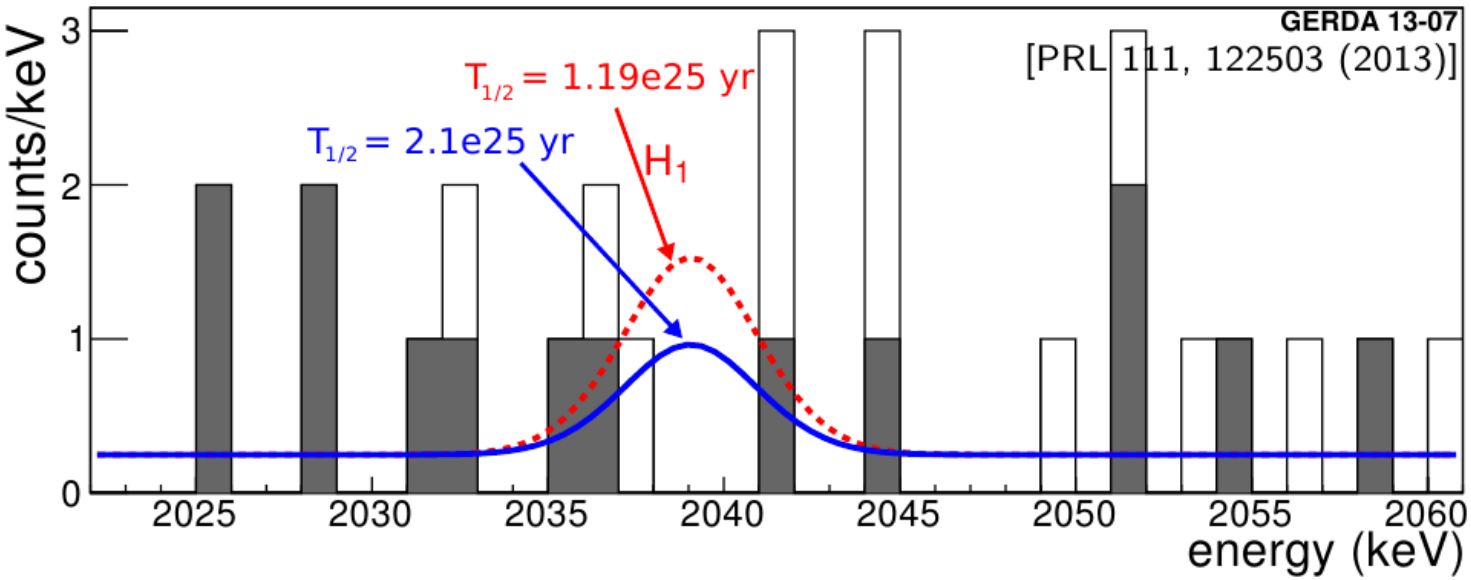
Bayes:
$T_{1/2}^{0\nu\beta\beta} > 1.9 \cdot 10^{25}$ y at 90% C.I.
flat T prior $(0 - 10^{24} y) \rightarrow$ best fit $N_{0\nu} = 0$
(sensitivity = 2.0 1025 y)

Frequentist:
$T_{1/2}^{0\nu\beta\beta} > 2.1 \cdot 10^{25}$ y at 90% C.L.
profile likelihood fit $\rightarrow$ best fit $N_{0\nu} = 0$
(sensitivity = 2.4 1025 y)

Combining:
$T_{1/2}^{0\nu\beta\beta} > 3.0 \cdot 10^{25}$ y at 90% C.L.
GERDA + HdM + IGEX spectra

Comparison with Phys.Lett. B586 198 (2004) claim

Hypothesis test: H_1 ($T^{0\nu\beta\beta}_{1/2} = 1.19^{+0.37}_{-0.23} \cdot 10^{25}$ y + bkg) vs H_0 (bkg only)



In $Q_{\beta\beta} \pm 2\sigma_E$ (after PSD):

expected 5.9±1.4 signal cts

expected 2.0±0.3 bkg cts

observed 3 cts

GERDA only:
- profile likelihood $P(N_{0\nu\beta\beta} = 0|H_1) = 0.01$
- Bayes factor $P(H_1)/P(H_0) = 2.4 \cdot 10^{-2}$

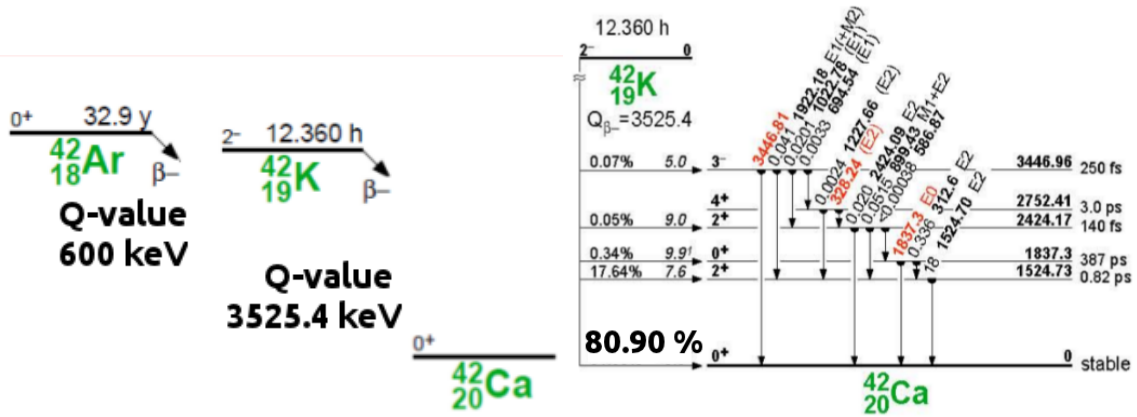
GERDA+IGEX+HdM:
- Bayes factor $P(H_1)/P(H_0) = 2 \cdot 10^{-4}$

—> claim strongly disfavoured

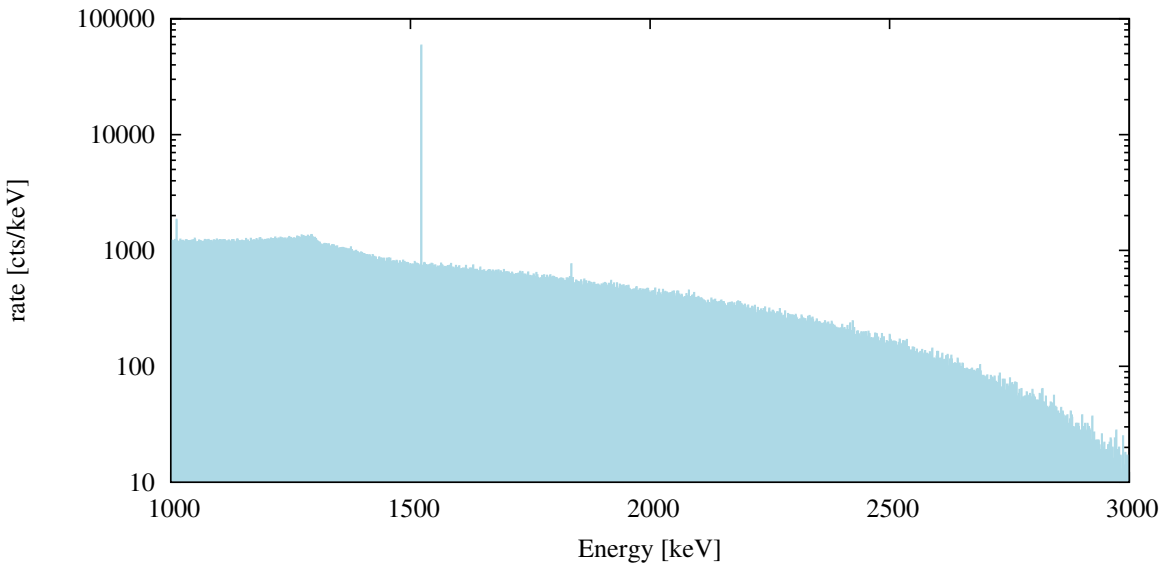
$T^{0\nu\beta\beta}_{1/2}$ from Mod. Phys. Lett. A 21 (2006) 1547 is not considered because of inconsistencies (i.e. missing efficiency factors, problem in the conversion from counts to $T^{0\nu\beta\beta}_{1/2}$) pointed out in Ann. Phys. 525 (2013) 269

^{42}K in GERDA

Cosmogenic ^{42}Ar (32.9 yr), followed by ^{42}K (12.36 h)



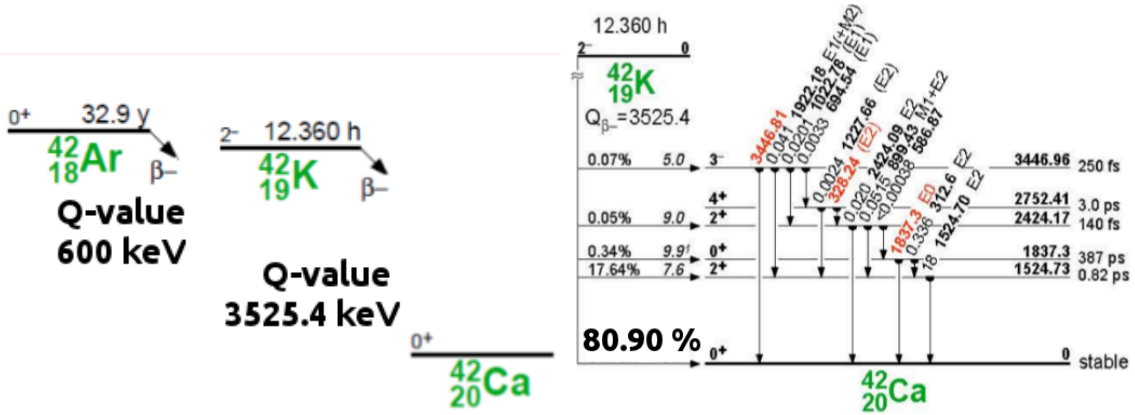
Monte Carlo - ^{42}K on detector surface in LAr



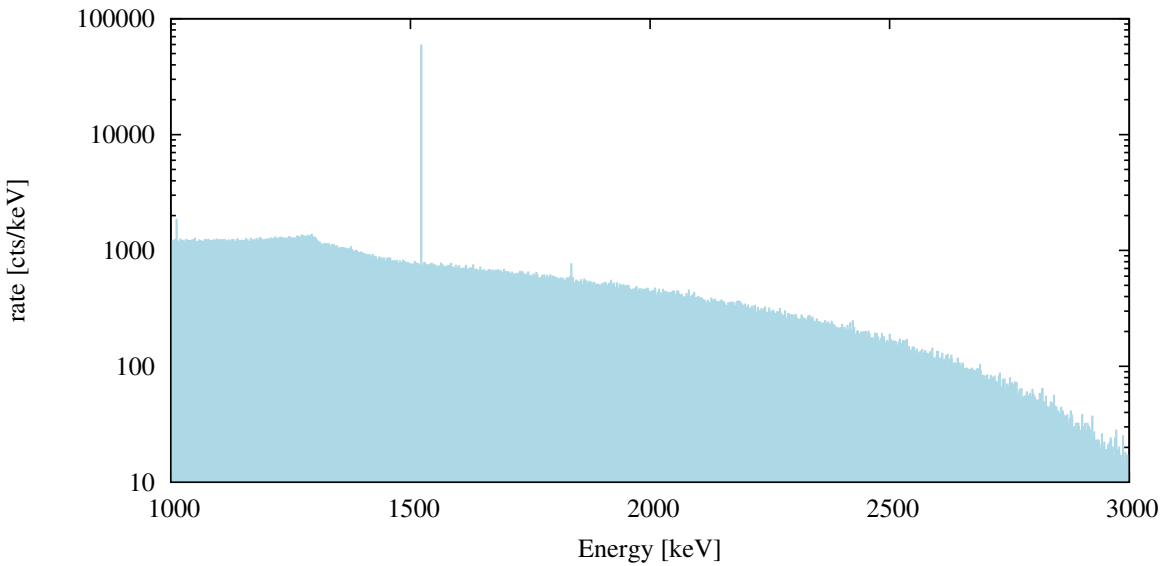
Phase I copper mini-shroud

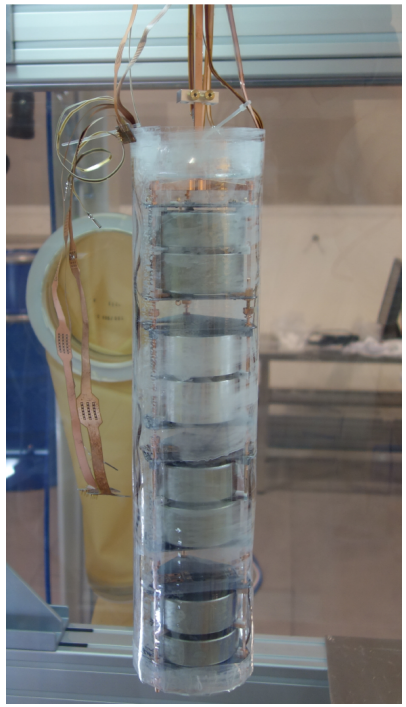
^{42}K in GERDA

Cosmogenic ^{42}Ar (32.9 yr), followed by ^{42}K (12.36 h)



Monte Carlo - ^{42}K on detector surface in LAr

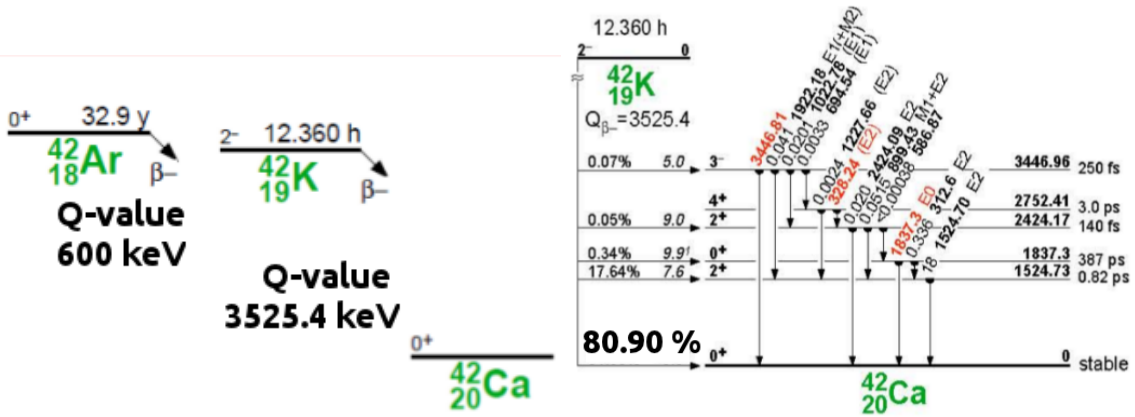




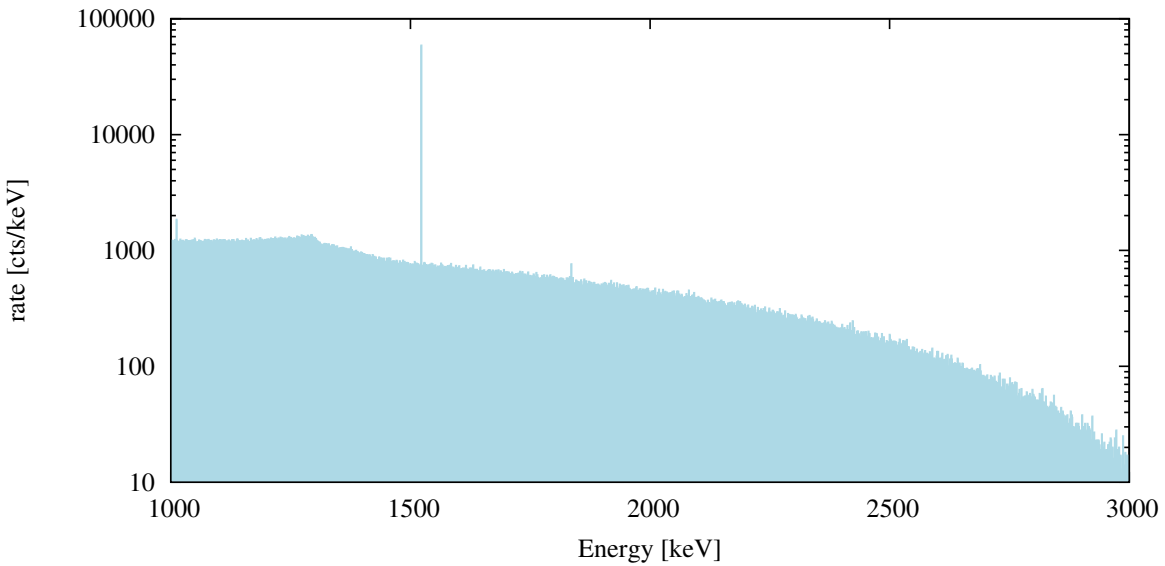
Nylon mini-shroud with wavelength shifter

^{42}K in GERDA

Cosmogenic ^{42}Ar (32.9 yr), followed by ^{42}K (12.36 h)



Monte Carlo - ^{42}K on detector surface in LAr



Nylon mini-shroud with wavelength shifter

Surface background (^{42}K)

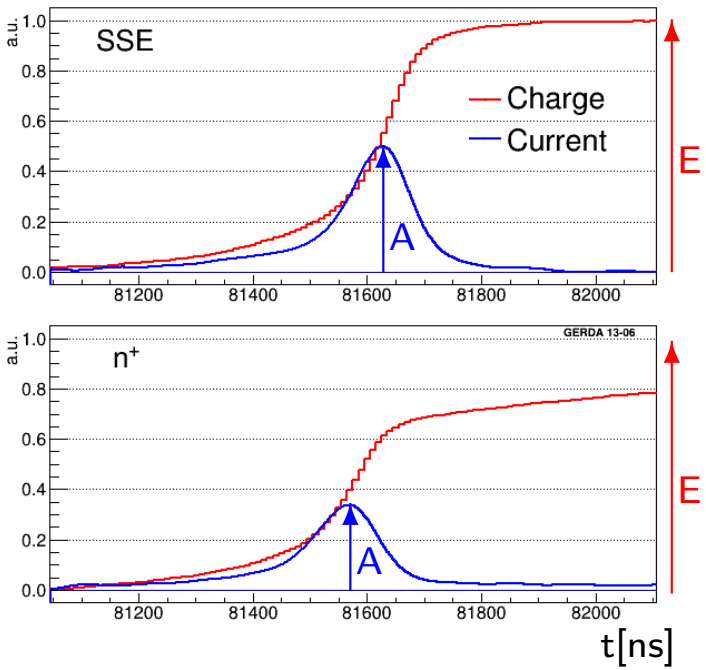
n+ surface pulses

Longer charge collection

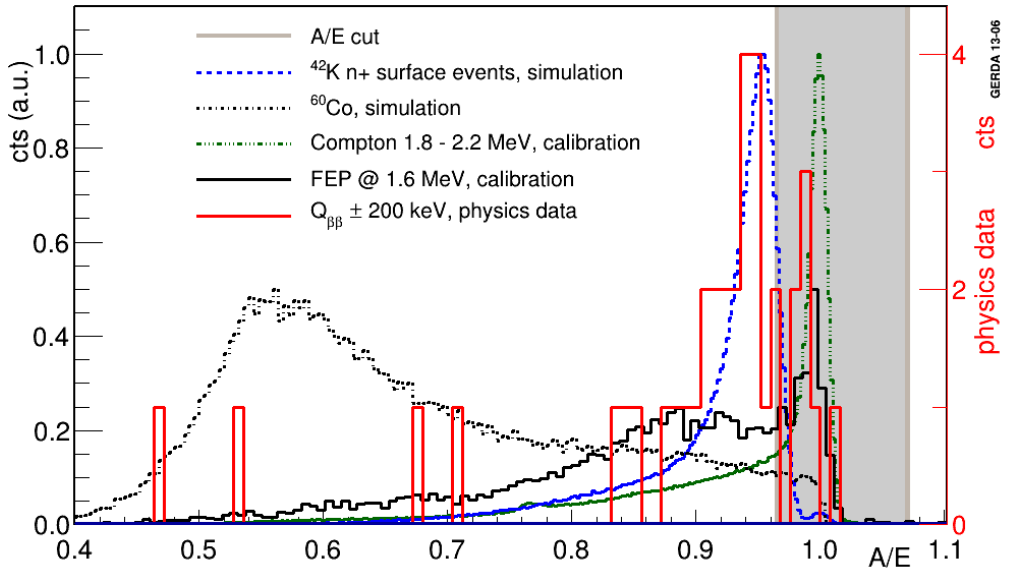
Efficient pulse shape discrimination

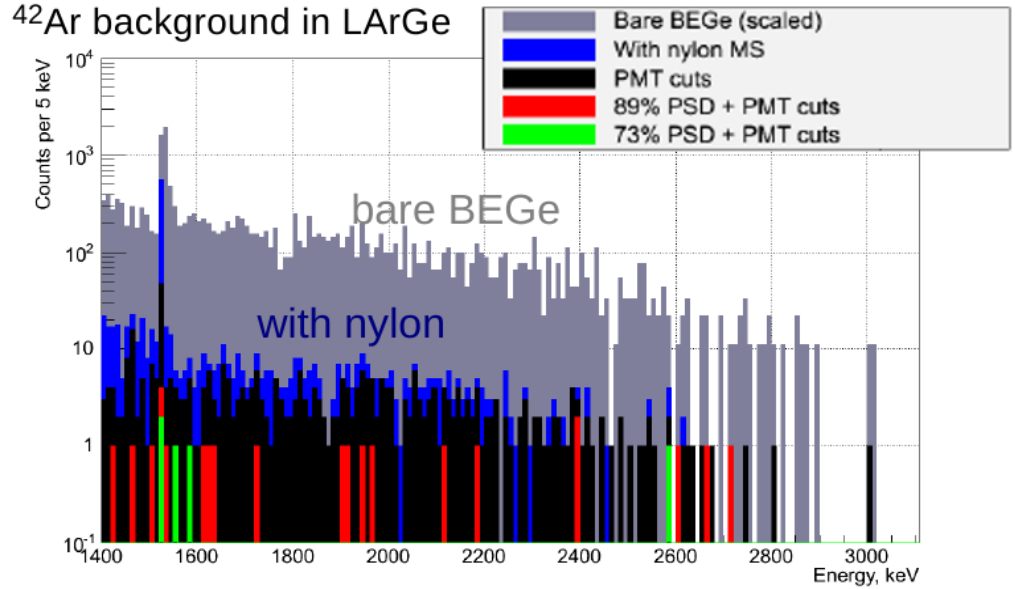
Phase I BEGe SF: 8

Test with β-emitter SF: $\sim$100



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



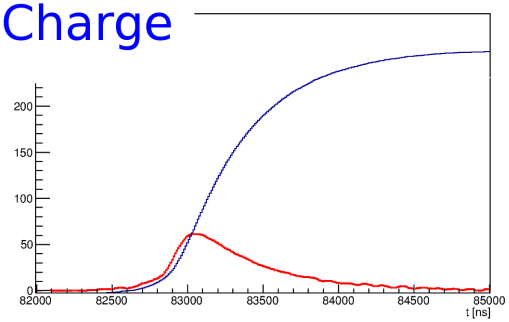


BEGe's PSD: Current and Charge Amplitudes Ratio (A/E)

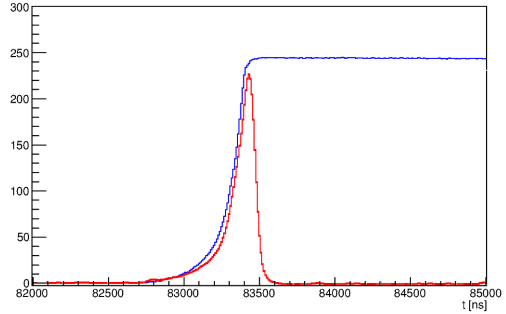
Current

Charge

background

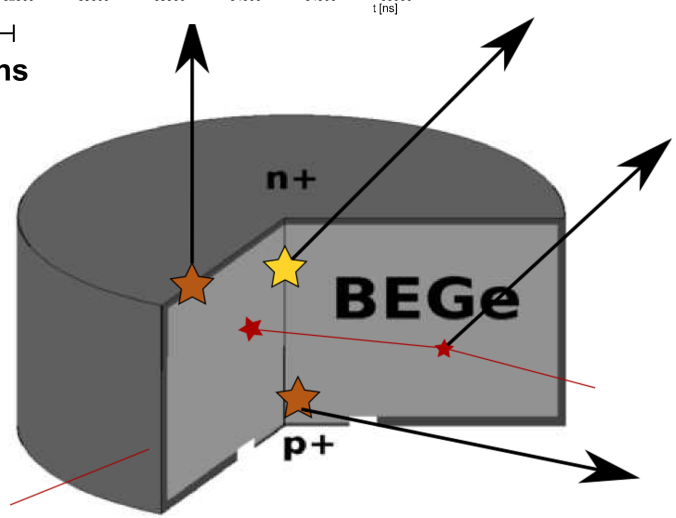


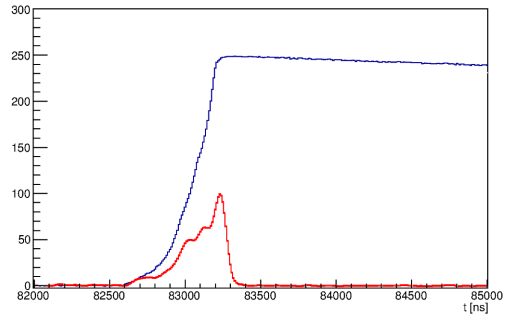
300 ns



$0\nu\beta\beta$ signals

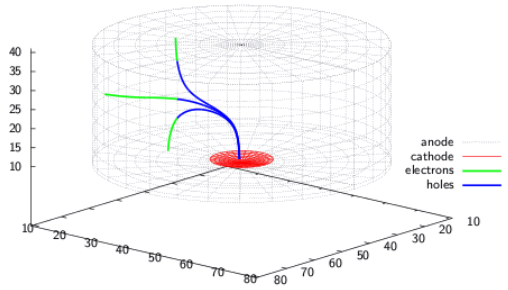
300 ns

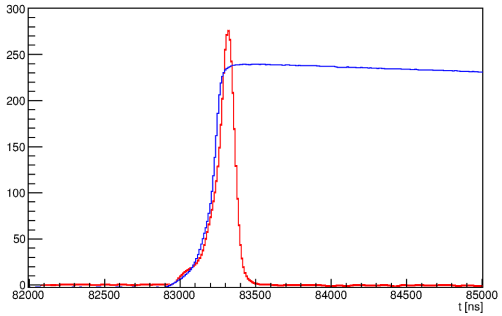




background

300 ns





background

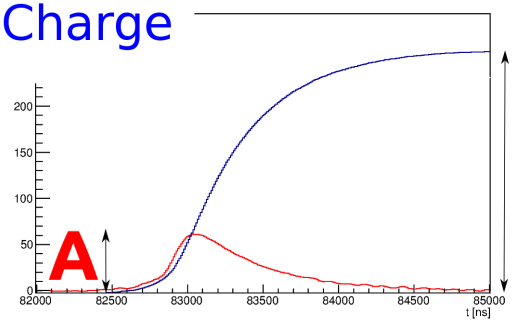
300 ns

BEGe's PSD: Current and Charge Amplitudes Ratio (A/E)

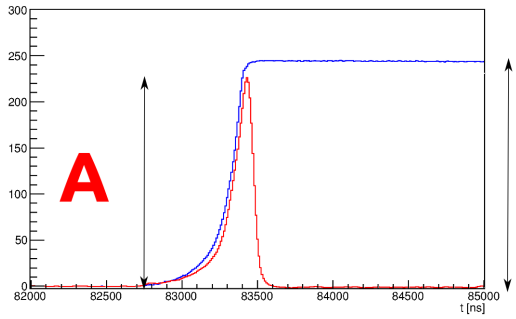
Current

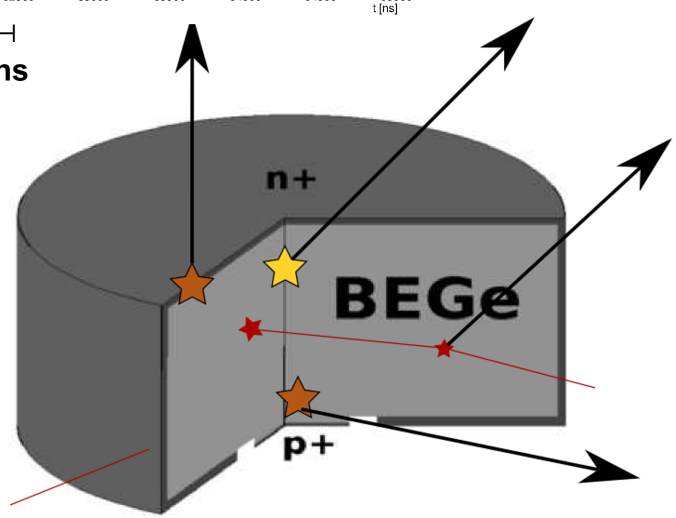
Charge

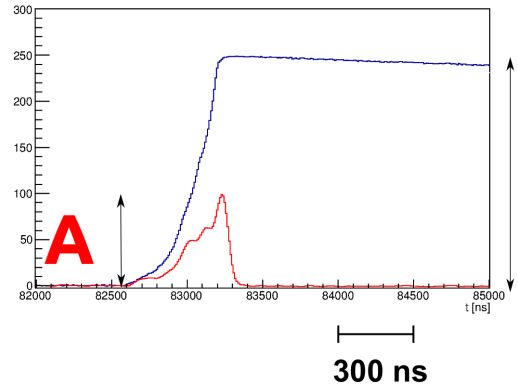
background



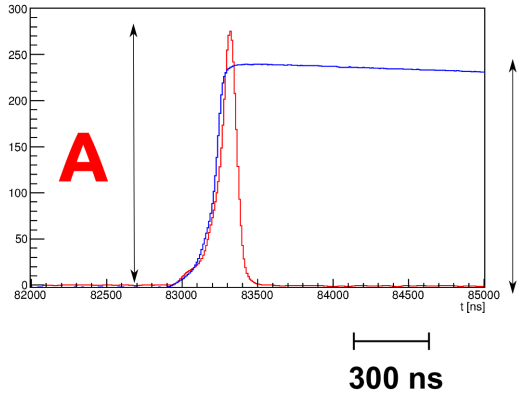
$0\nu\beta\beta$ signals







background



background