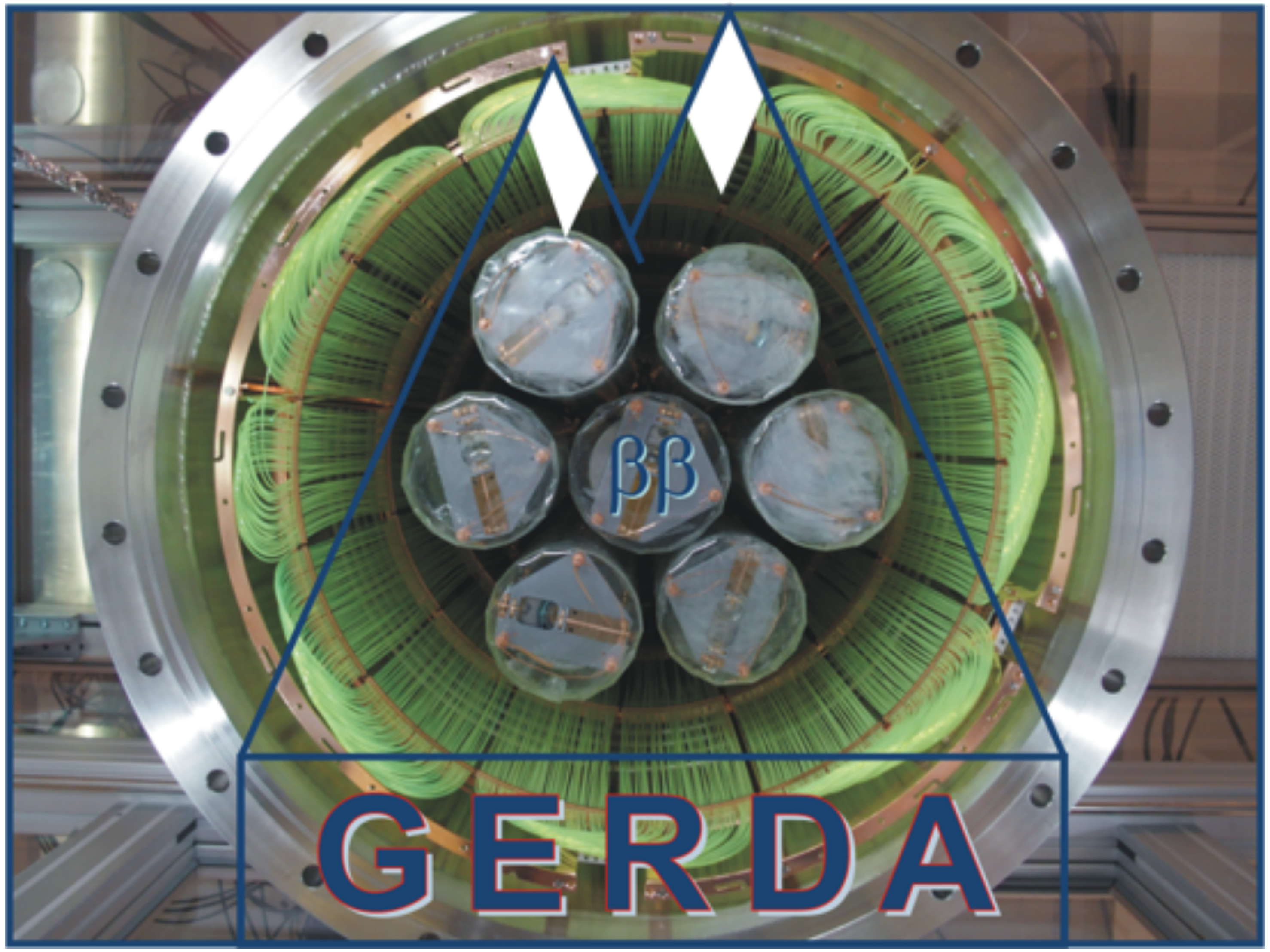


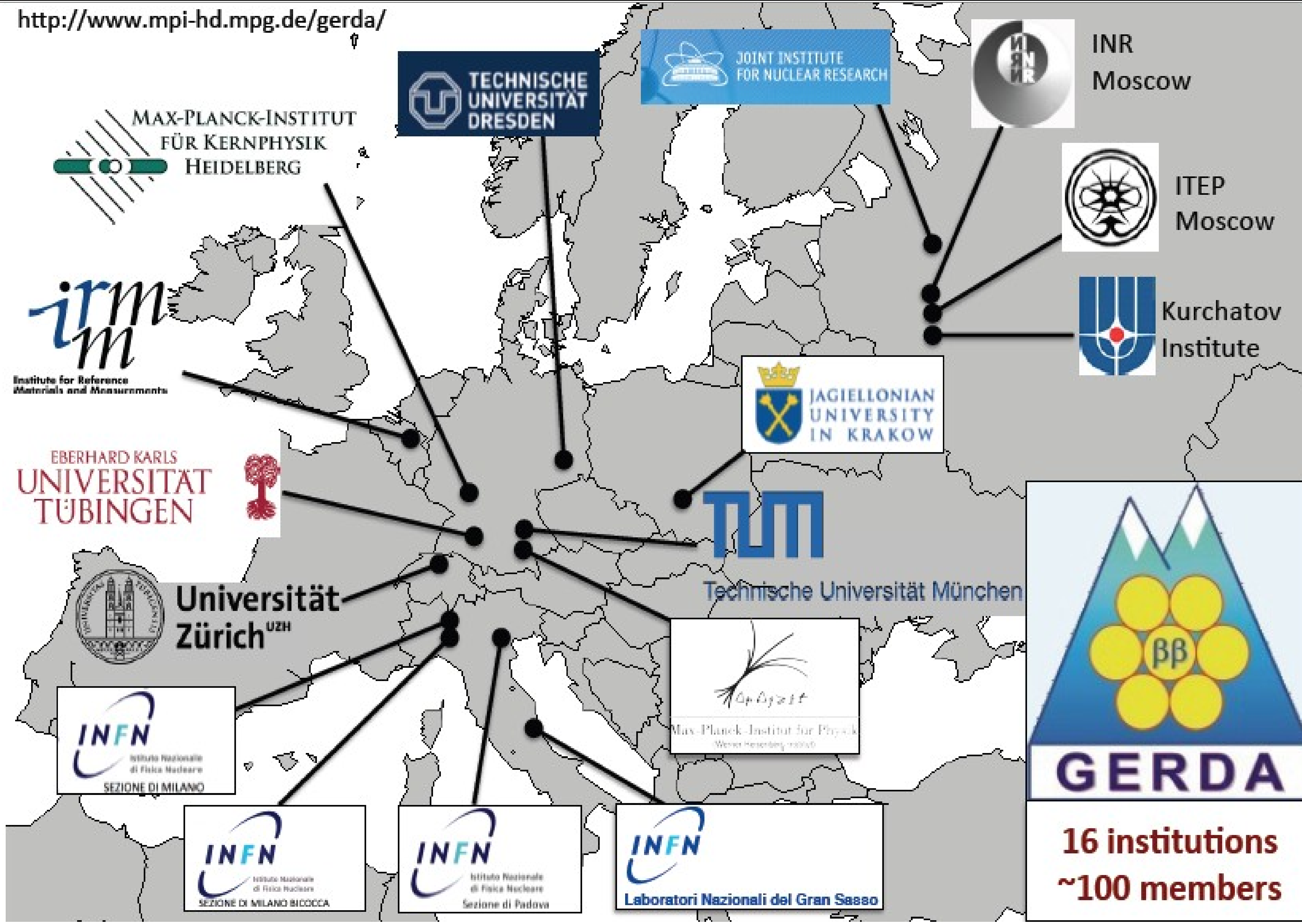
Background free search for neutrinoless double beta decay with GERDA Phase II

József Janicskó Csáthy for the GERDA collaboration

Technische Universität München

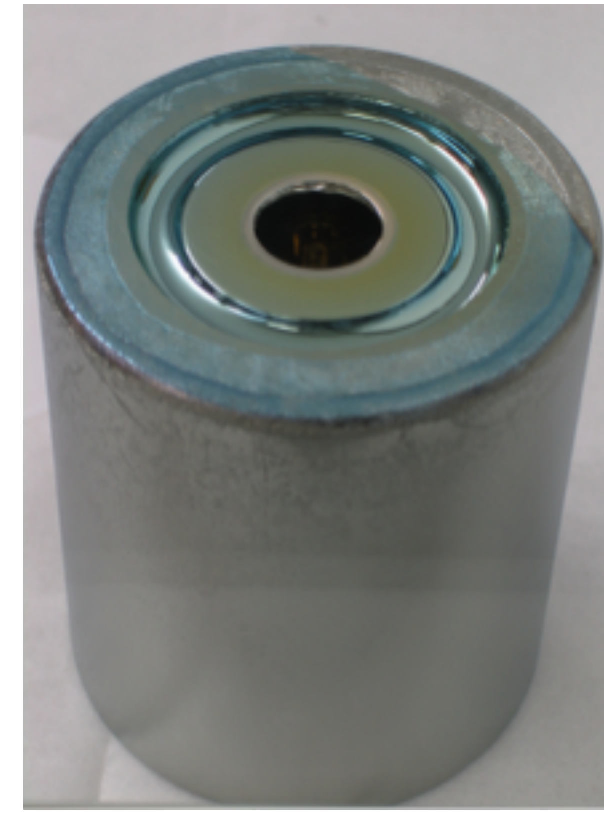
GERDA

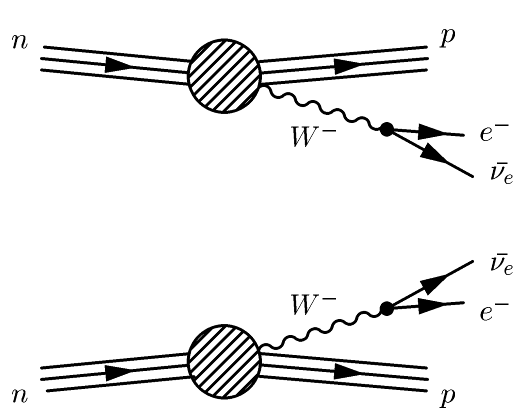
http://www.mpi-hd.mpg.de/gerda/

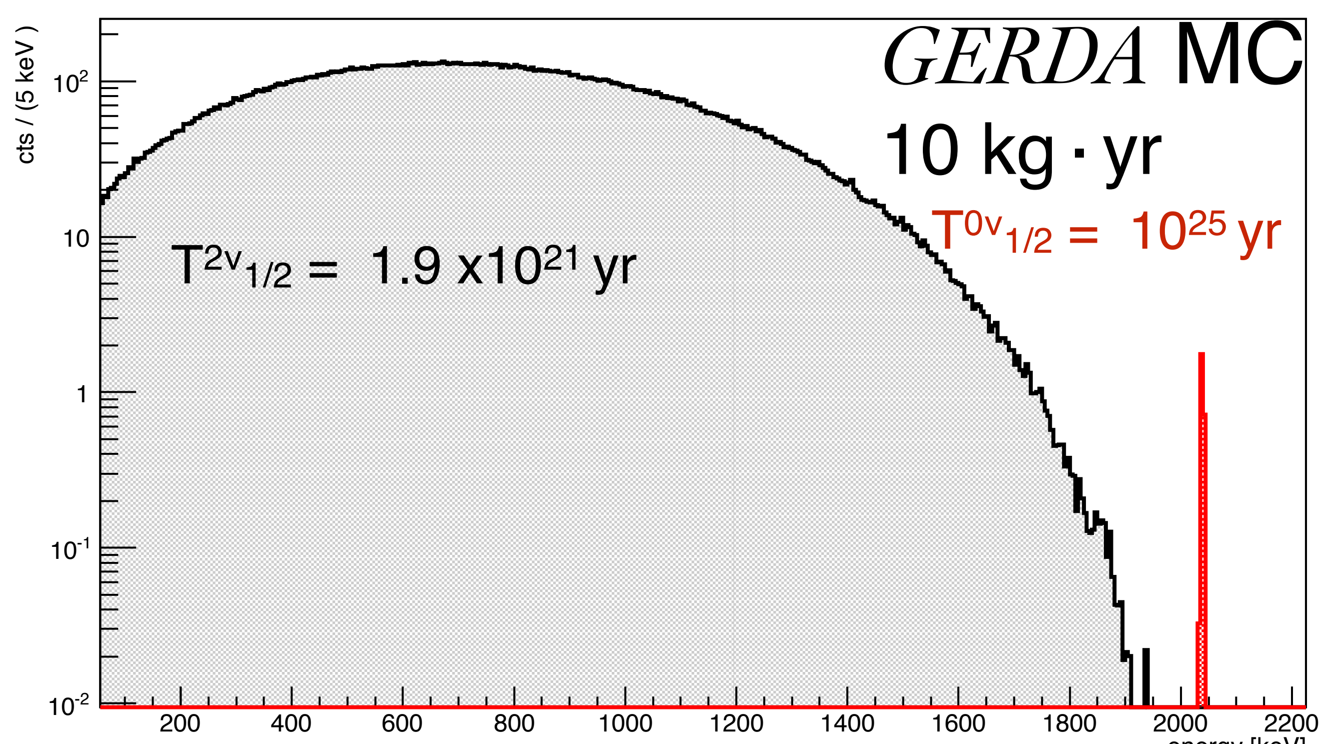


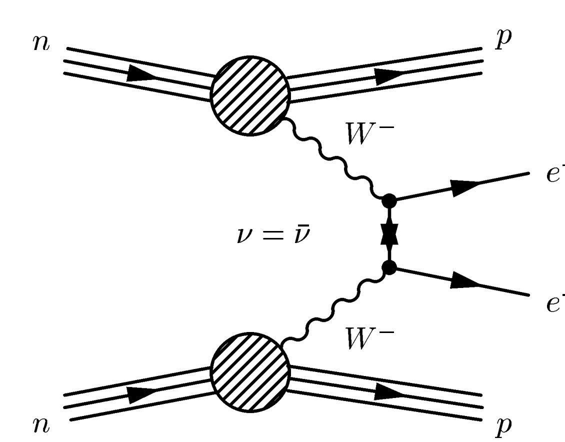
GERDA

- Search for neutrino-less double beta decay in Ge-76
- GERDA uses HPGe detectors enriched in Ge-76
- HPGe detectors have excellent resolution:
  - 2ν2β decay is not a background
  - in situ background reconstruction
  - high discovery potential - close to the sensitivity
- HPGe is a difficult but proven technology









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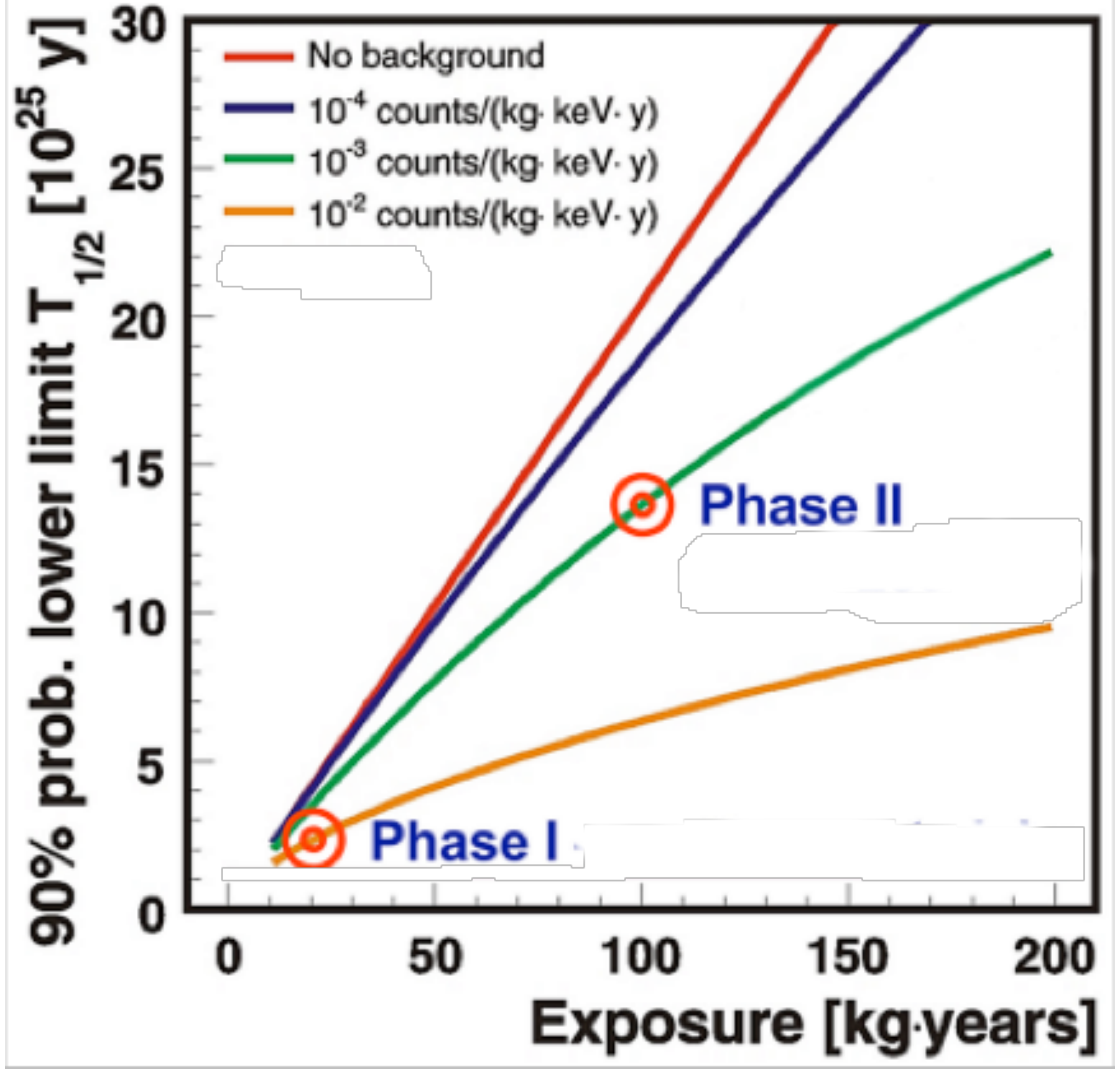
GERDA status

- *Status of Phase I*: data taking ended with 21.6 kg · yr exposure: run from Nov. 2011 to May 2013
- *Result of Phase I:* $T^{0\nu}_{1/2} > 2.1 \times 10^{25}$ yr
- *Goal of Phase II*: background level of 10^{-3} cts/(keV kg yr) and a half-life sensitivity of ~10^{26} yr
- *Phase II strategy to reduce background:* LAr scintillation light readout + pulse shape discrimination
- *Phase II status:* data taking since 2015, first data release: June 2016



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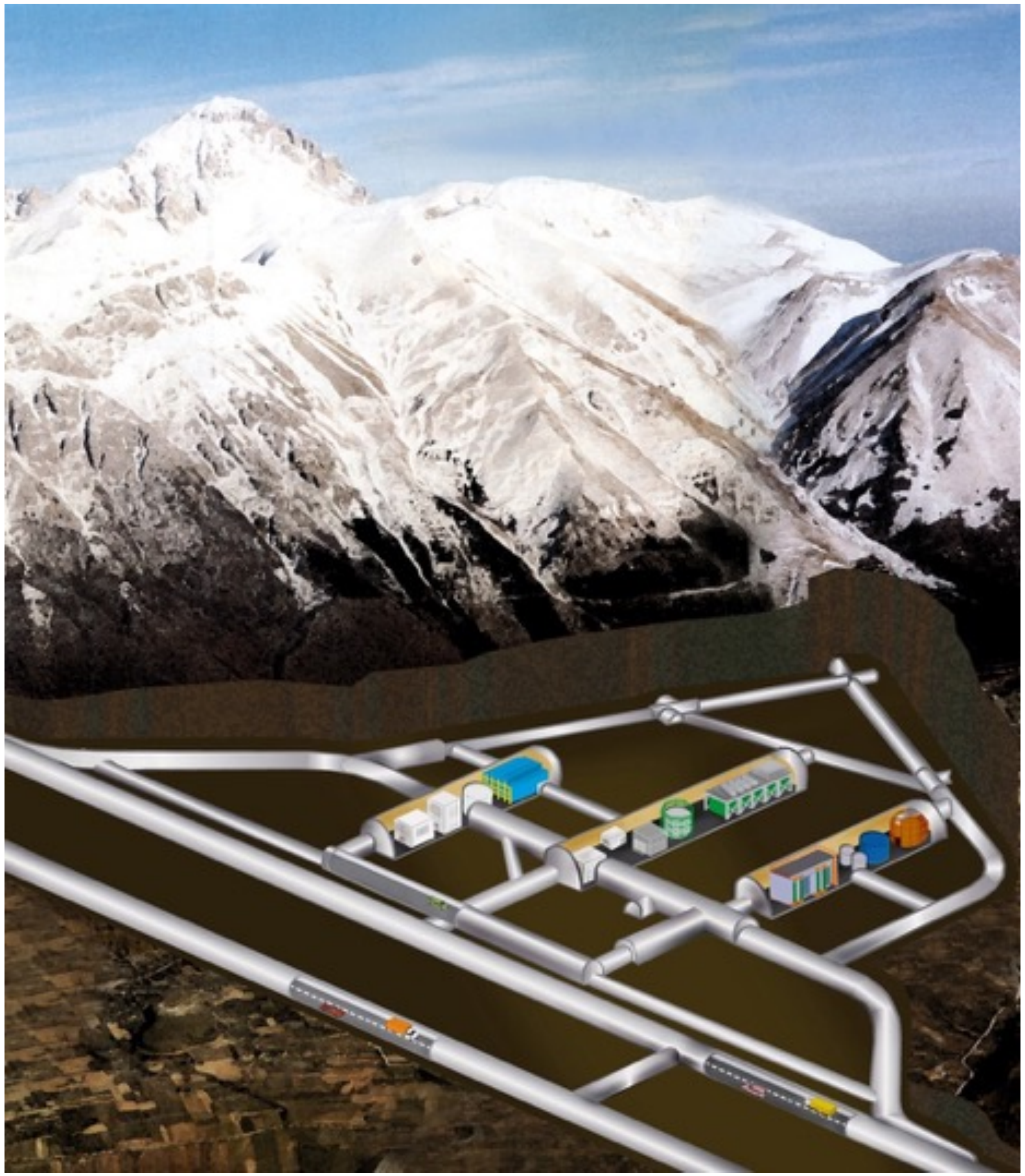
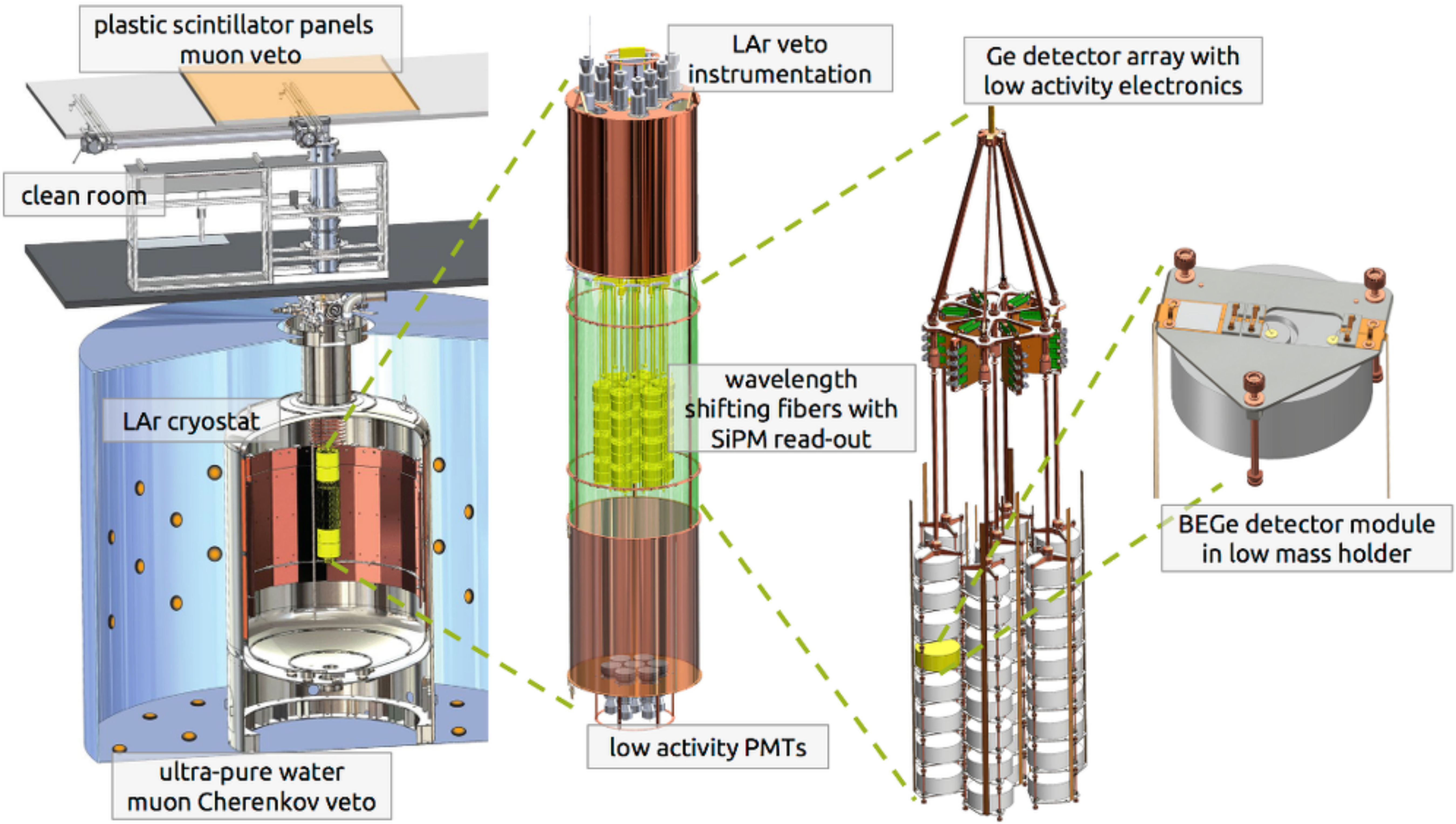
GERDA at LNGS

3500 m w.e. overburden

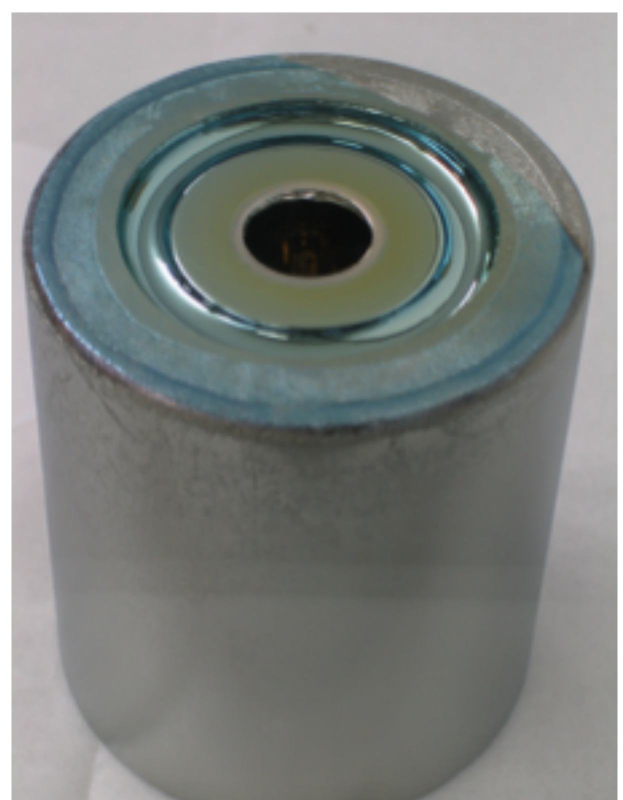


Gerda Phase II



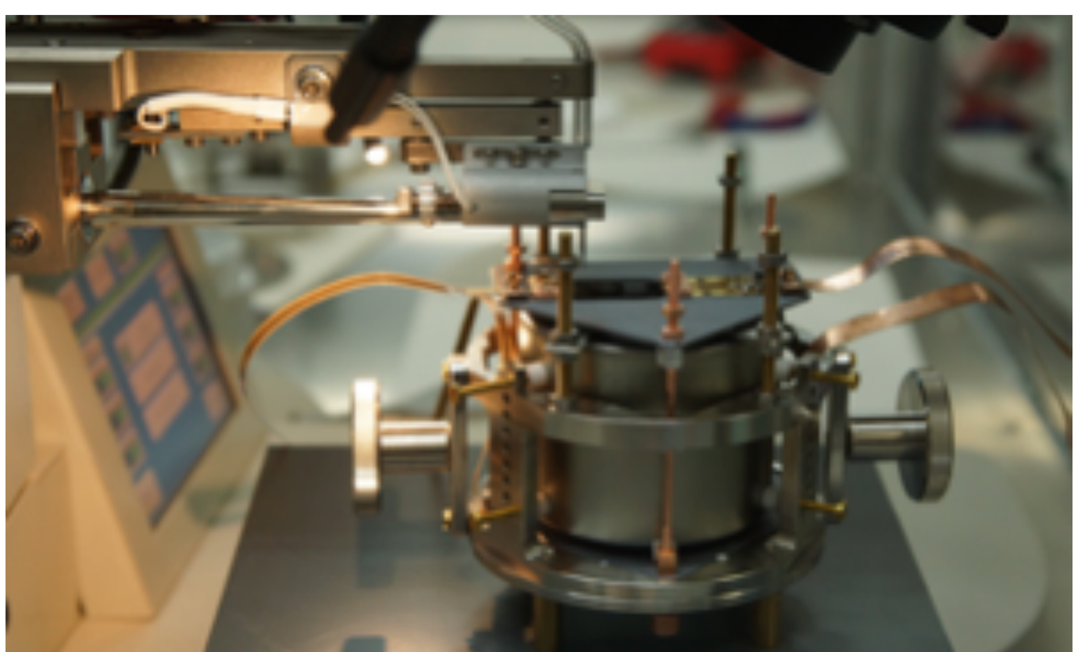
Phase II setup

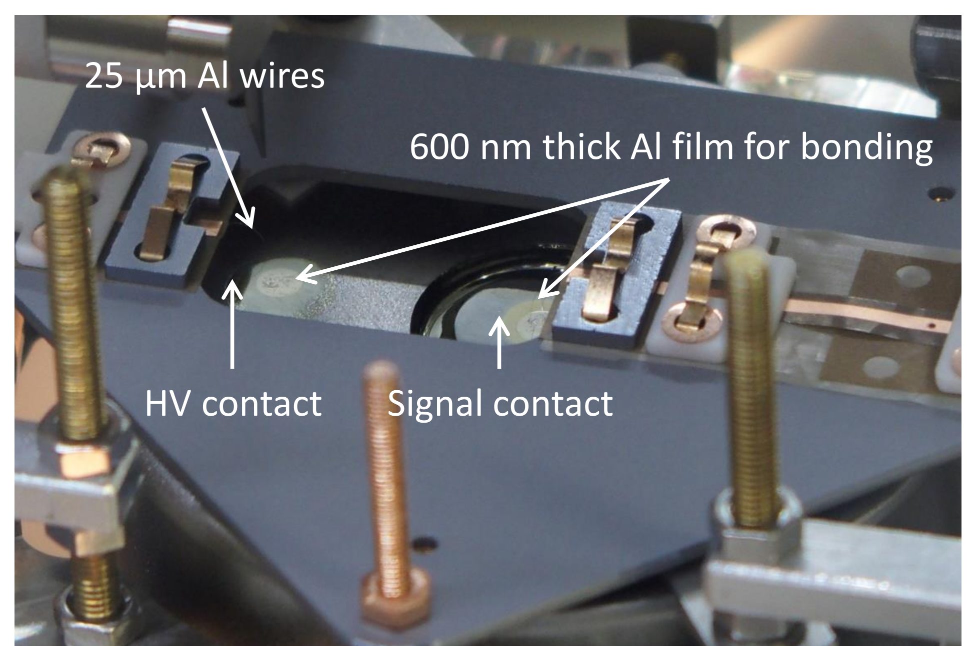
- *7* coaxial detectors, HdM and IGEX: 15.8 kg
- 30 new BEGe detectors, from new production total: 20 kg
- 3 natural coax: 7.6 kg
- Last integration test in Dec. 2015
- The experiment is alive since then



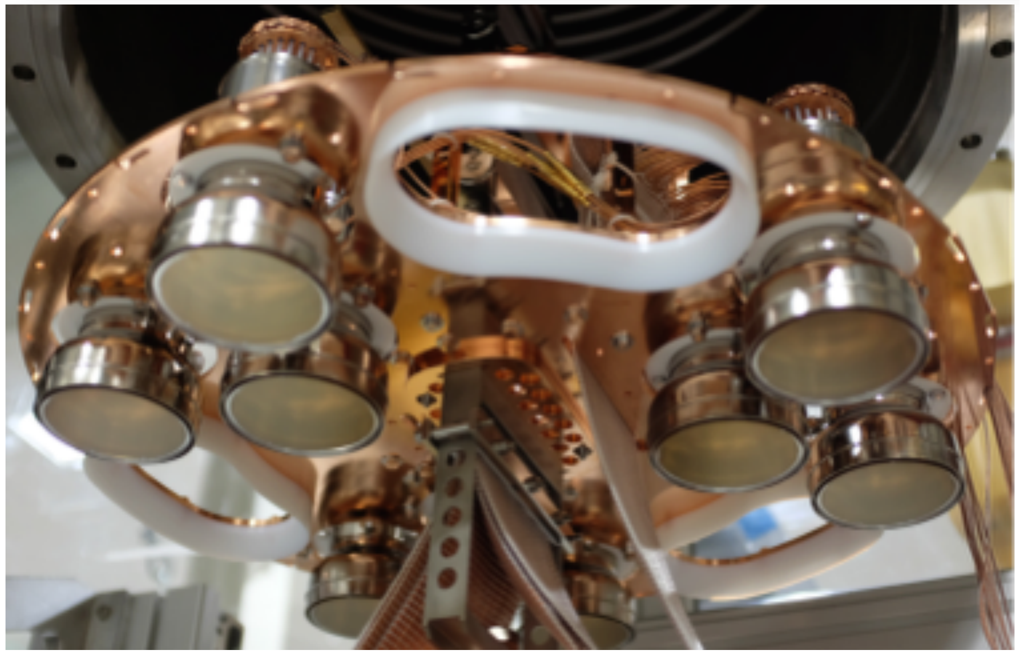
Upgrades for Phase II

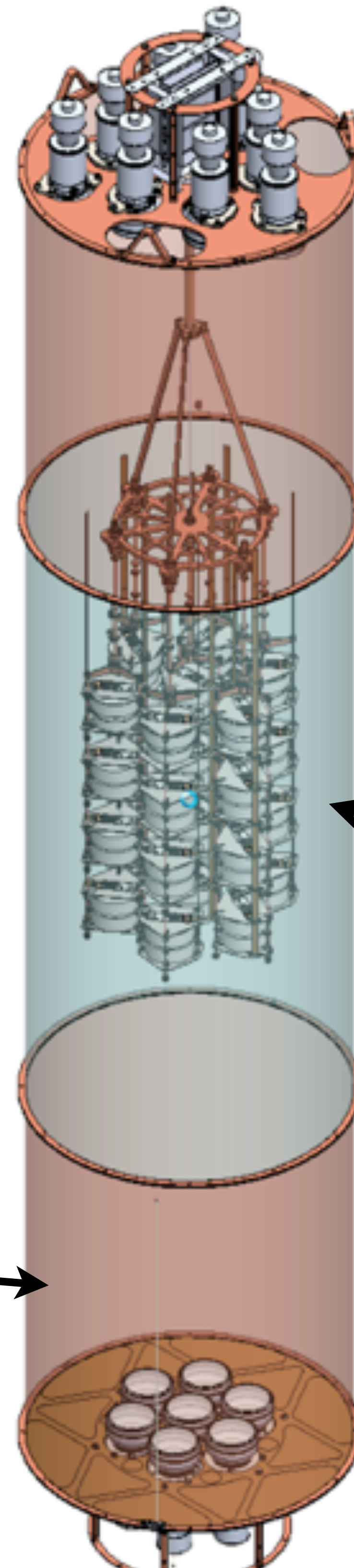
- 30 new BEGe detectors need new holders
- New holder made of silicon plates
  - Silicon is cleaner
  - 3x less copper than in the Phase I holder
- Detector contacting with wedge bonding
- String wrapped in WLS coated nylon
  - Reduces ^{42}K background



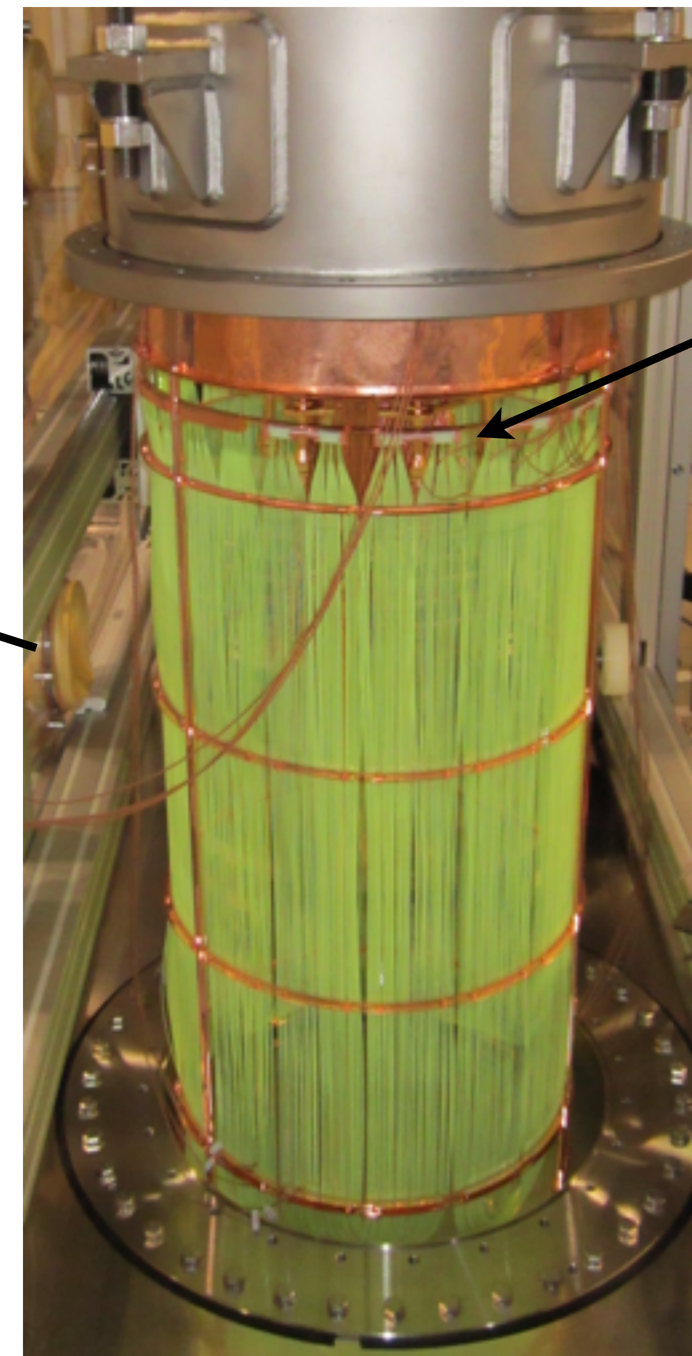


LAr - veto





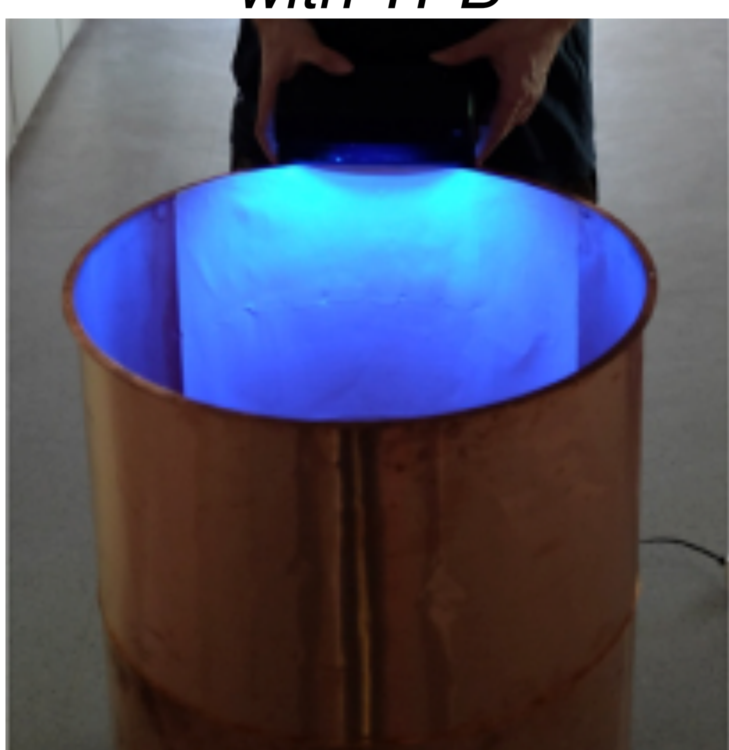
3” low-background PMT
Hamamatsu R11065-20



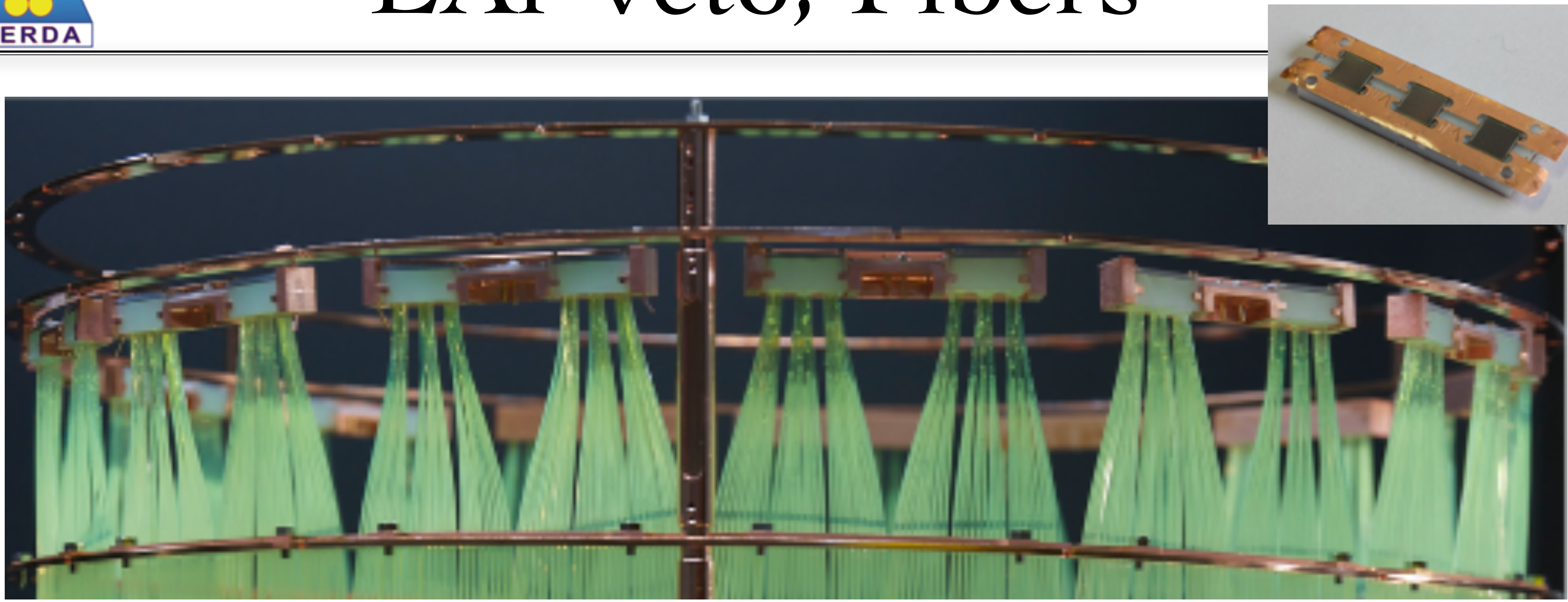
SiPMs

Fiber “shroud”
800 m WLS
fibre coated
with TPB

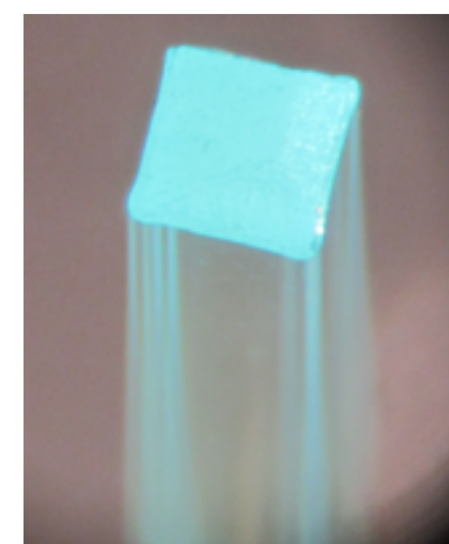
Copper “shroud” with
Tetratex reflector coated
with TPB



LAr-veto, Fibers



- ~800 m BCF-91A square WLS fiber, total surface: ~3 m^2
- coated with TPB, vacuum deposition
- Total activity of the fibres ~80 μBq
- Low background SiPMs packaging done at TUM, SiPMs in die from Ketek GmbH.



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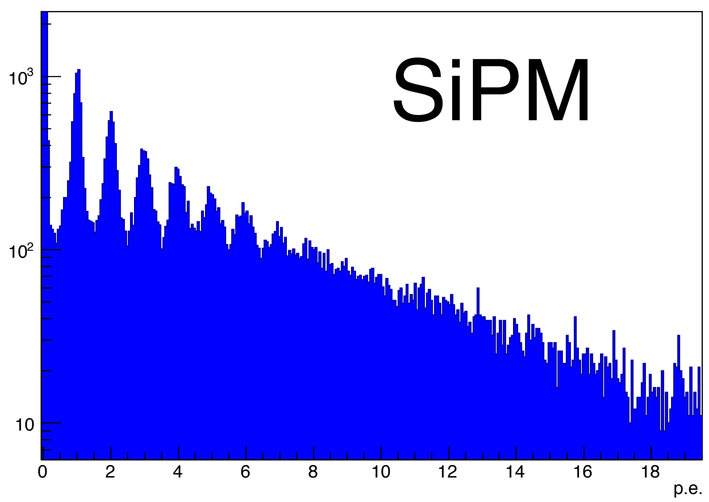
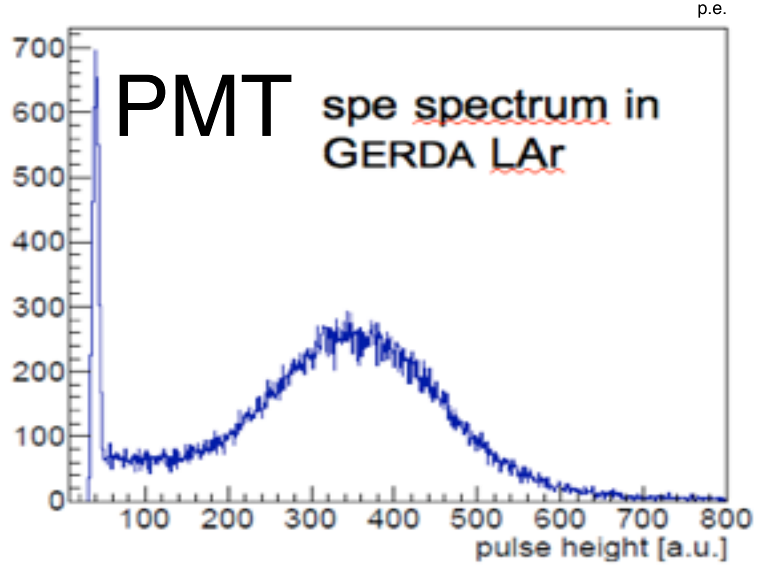
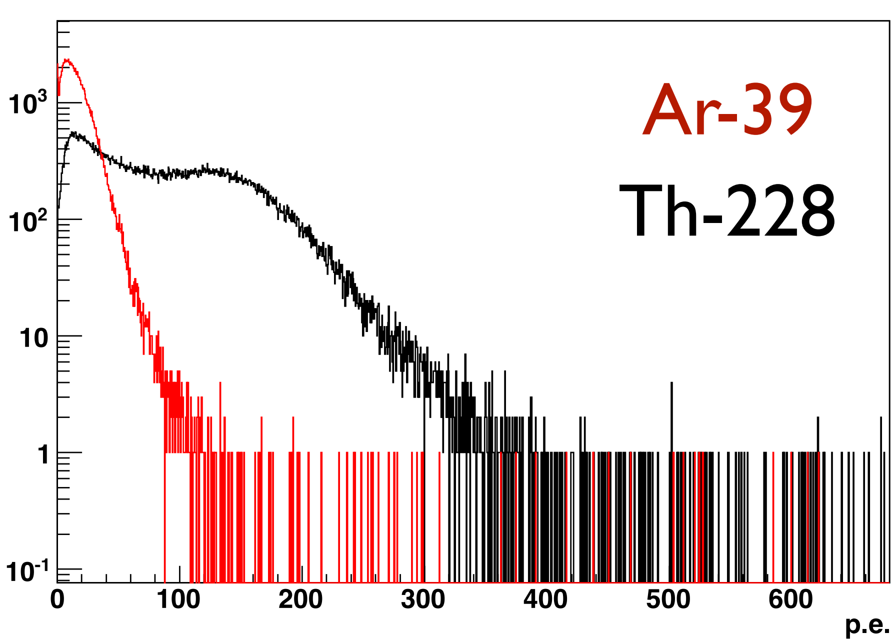
LAr veto commissioning

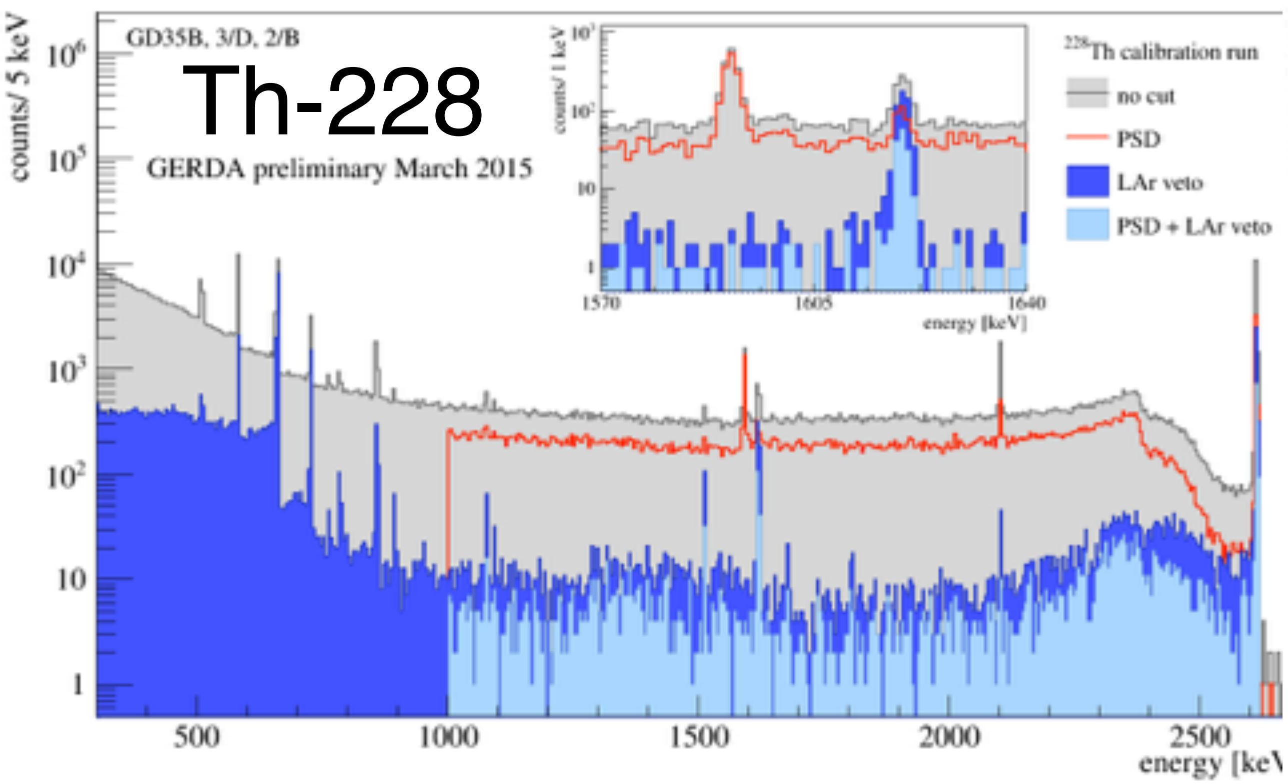


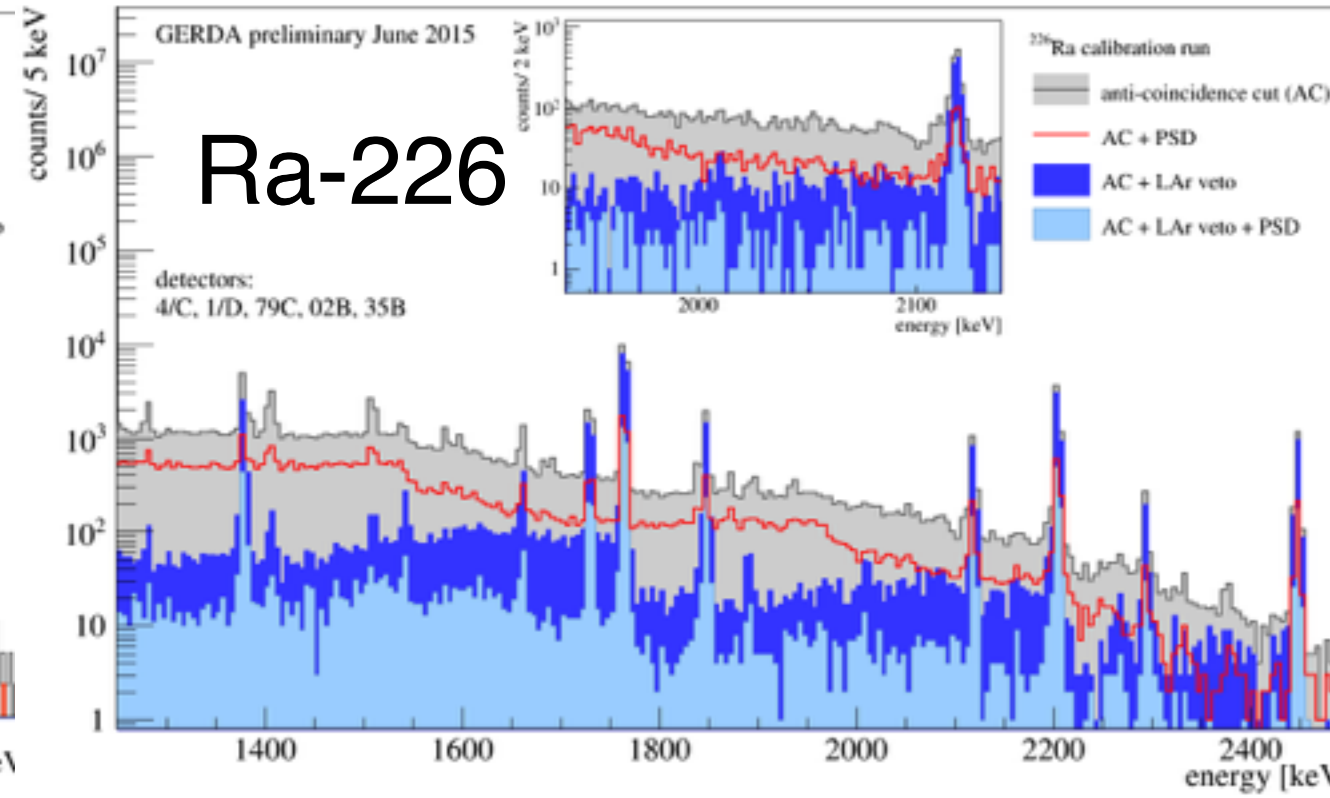




- "Photo-electron" peaks recognisable in the amplitude spectrum - in both SiPMs and PMTs spectra
- Veto on one photo-electron in any channel
- After single channels calibrated and summed up: light yield: 50 - 60 p.e./MeV - with ^{228}Th source
- Count rate dominated by ^{39}Ar
- LAr -veto Suppression Factor tested with one detector string with ^{228}Th and ^{226}Ra sources

LAr veto commissioning





- LAr-veto mounted in Nov. 2014, several calibration runs.
- Trigger on single photoelectron, both PMTs and SiPMs
- Very effective for gamma background

Suppression of:	Ge Anti-Coincidence	LAr-veto	PSD	LAr + PSD	Acceptance
^{228}Th	1.26 ± 0.01	97.9 ± 3.7	2.19 ± 0.01	344.6 ± 24.5	86.8%
^{226}Ra	1.26 ± 0.01	5.7 ± 0.2	2.98 ± 0.06	29.4 ± 2.5	89.9%

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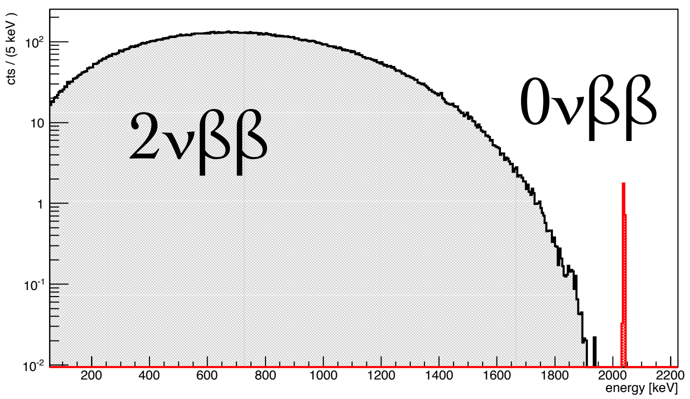
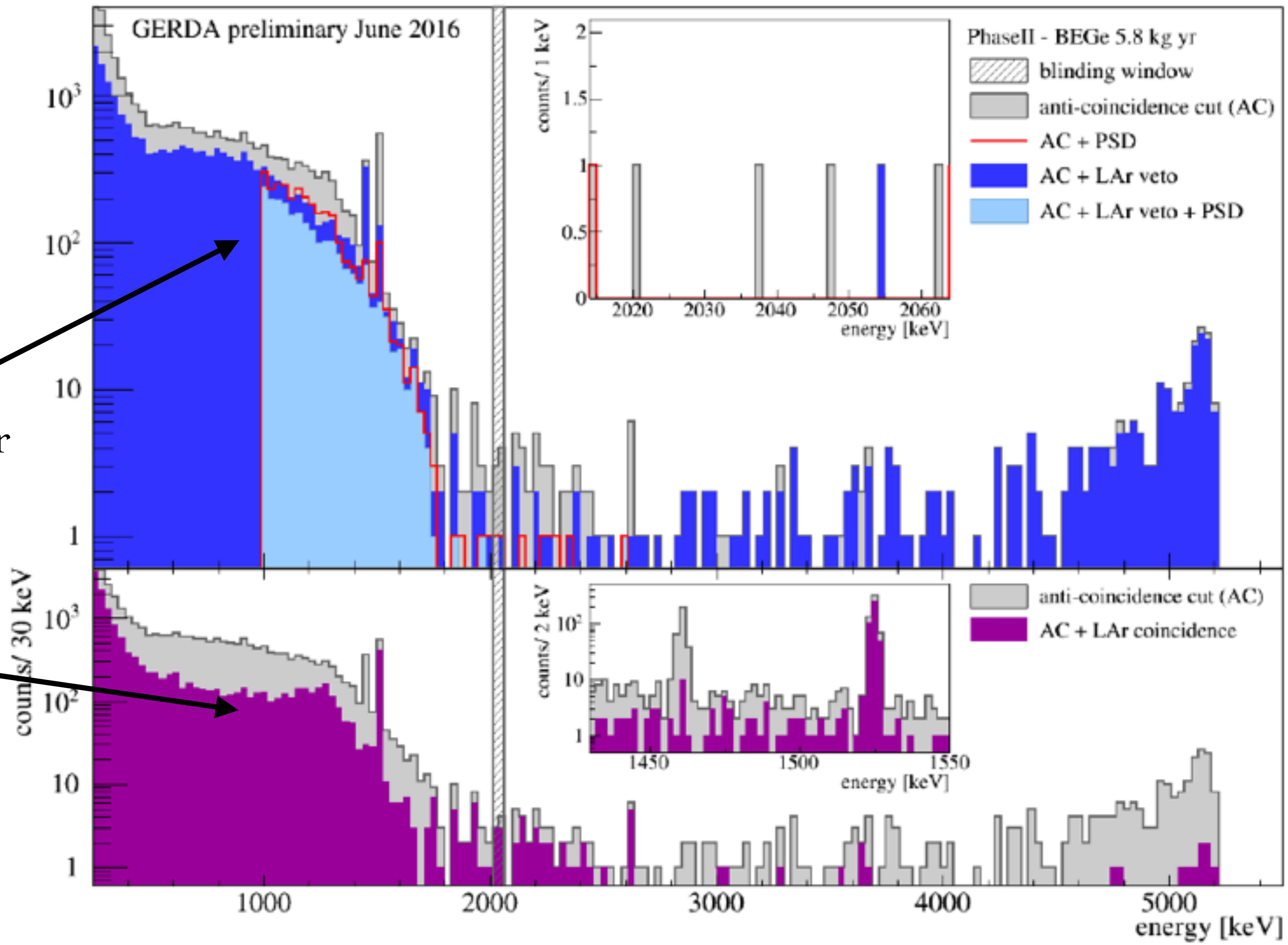
Phase II, first results



pure 2νββ sample after LAr-veto cut

LAr coincidence spectrum = K^{40}/K^{42} Compton continuum



 JJ, May. 2017

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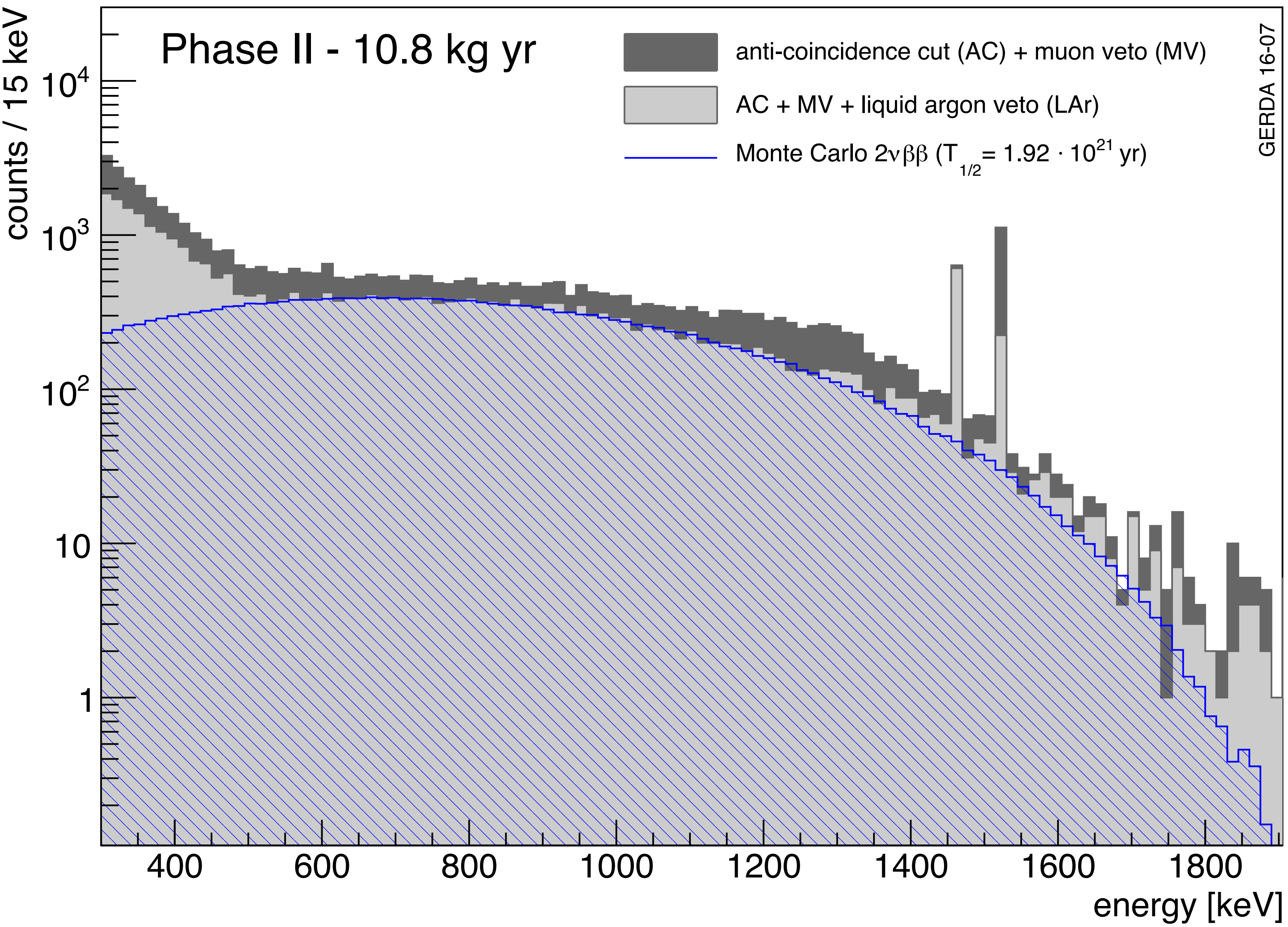
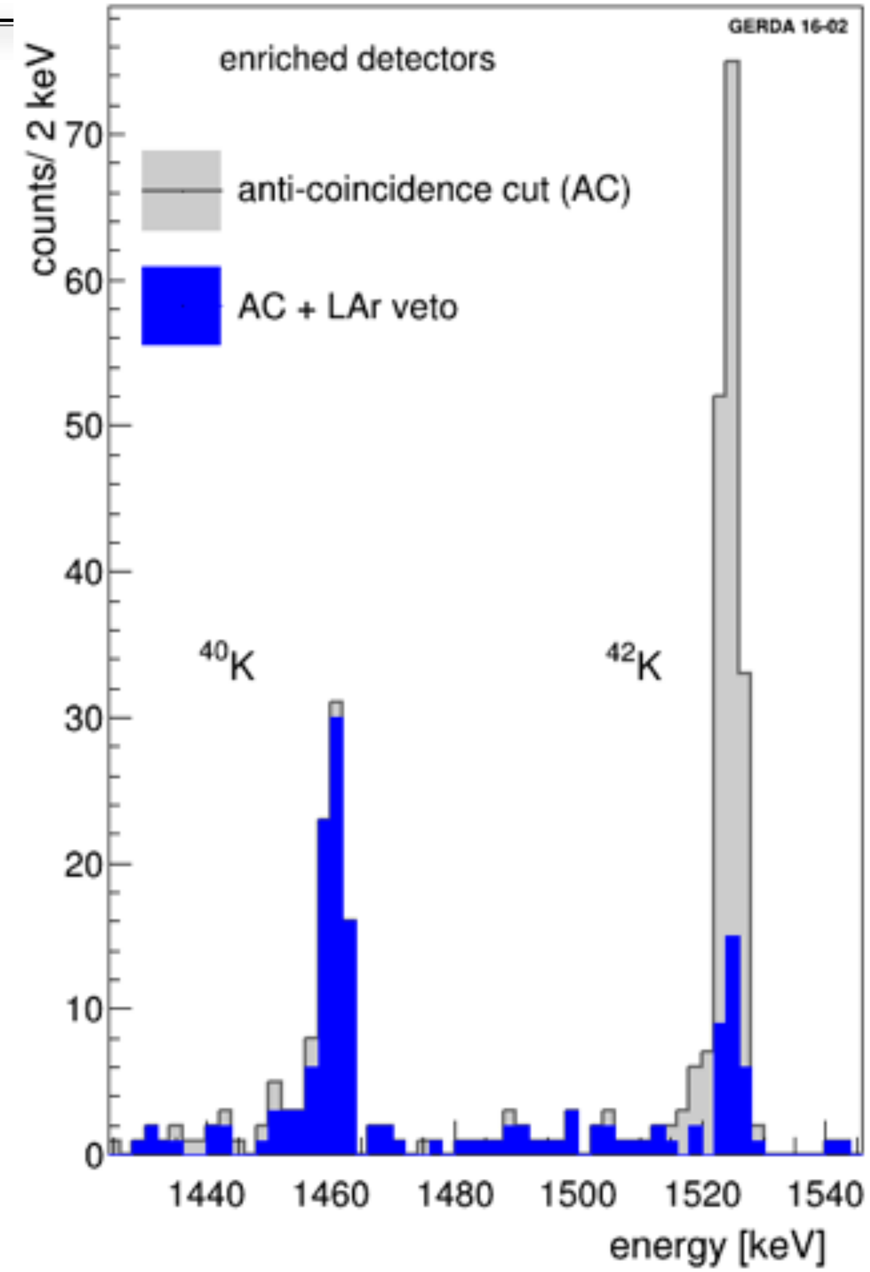
Phase II, first results





- LAr-veto works for background data as well
  - K^{40}/K^{42} Compton continuum strongly suppressed by LAr-veto
- Data agrees with $T_{1/2}(2\nu\beta\beta) = 1.9{\cdot}10^{21}$ yr from GERDA Phase I
- $2\nu\beta\beta$ events are used to validate PSD and active volume determination

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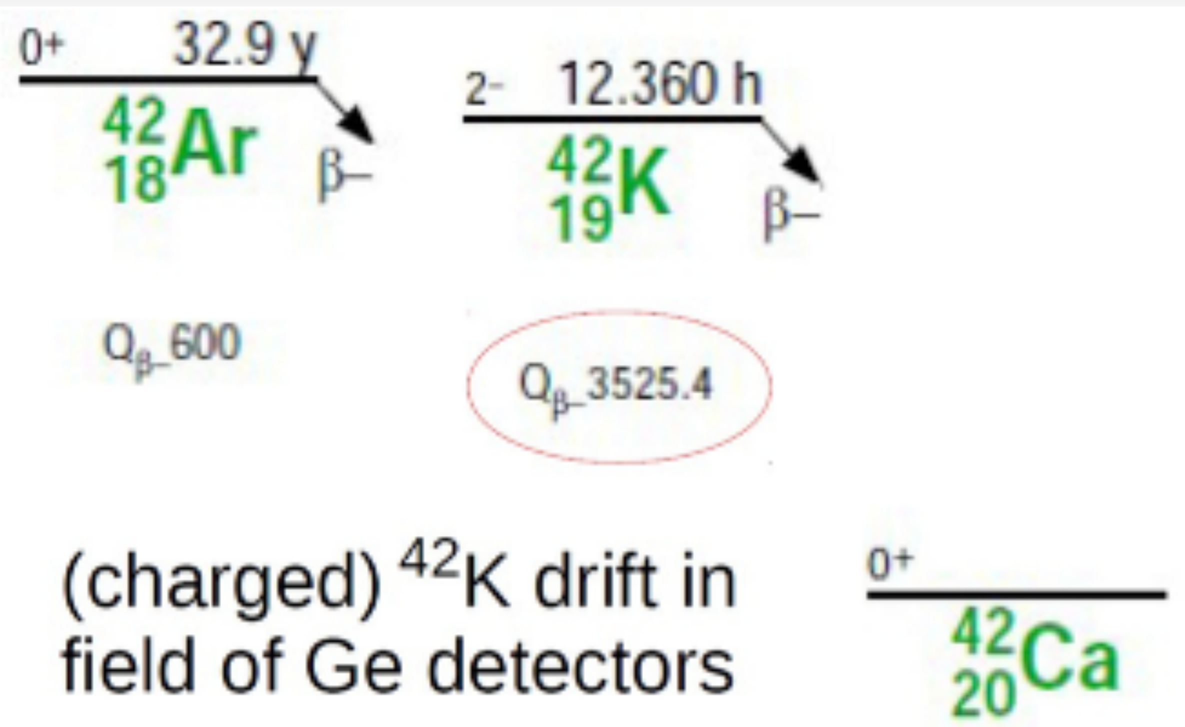
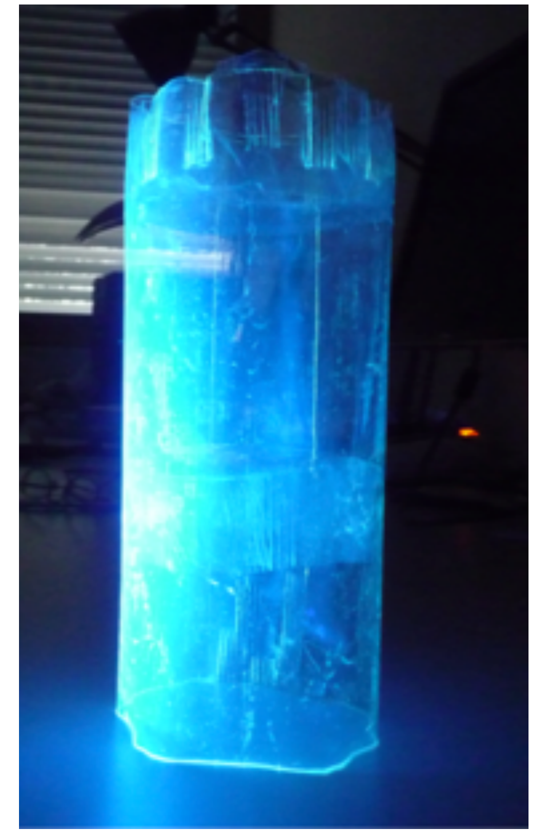
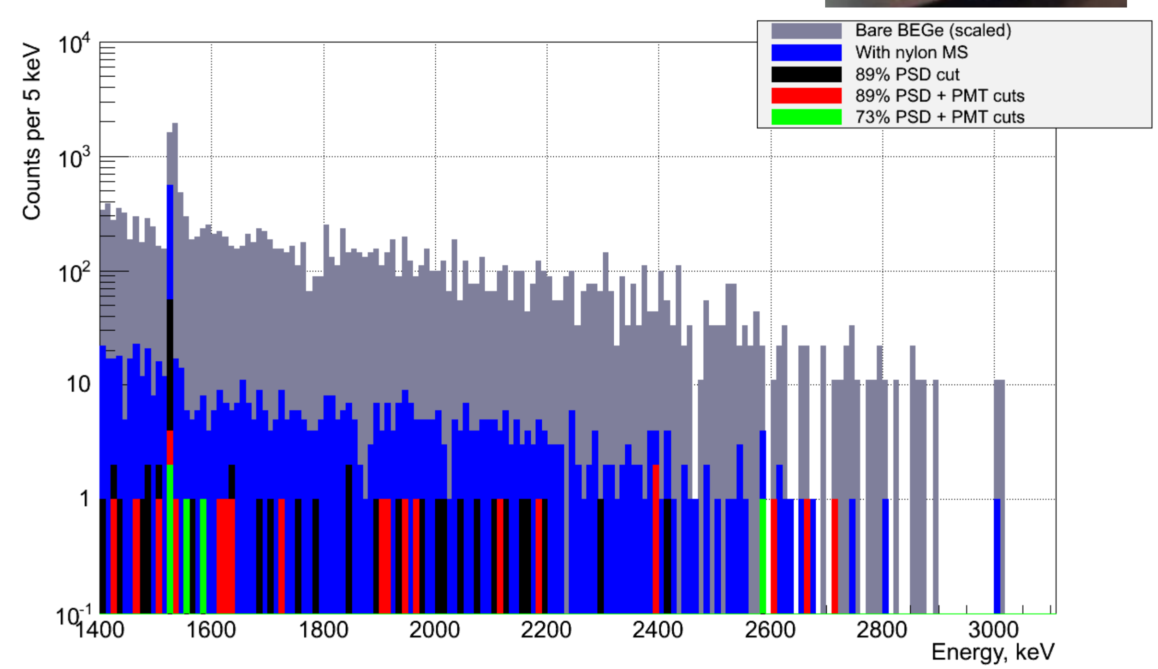
Ar-42 background

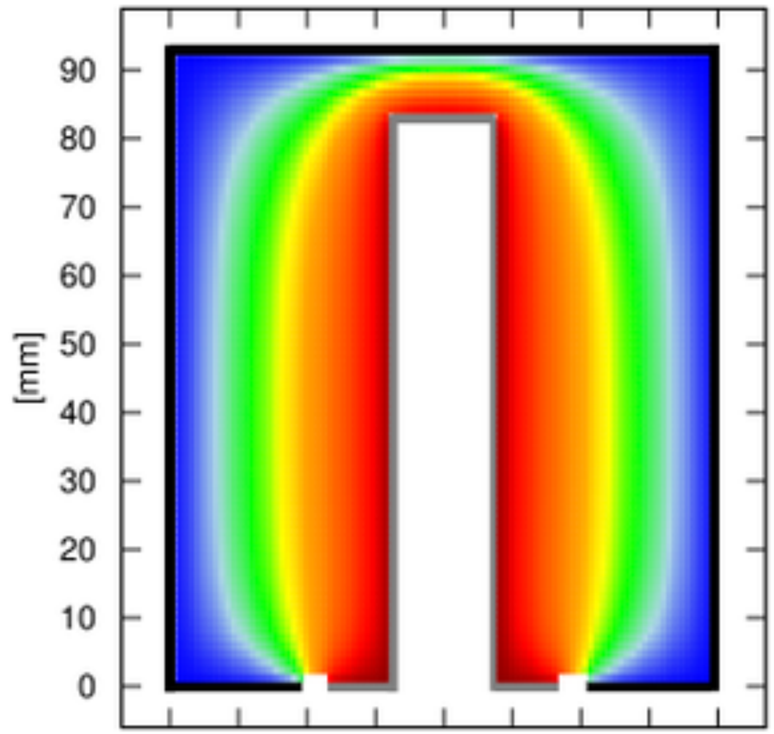




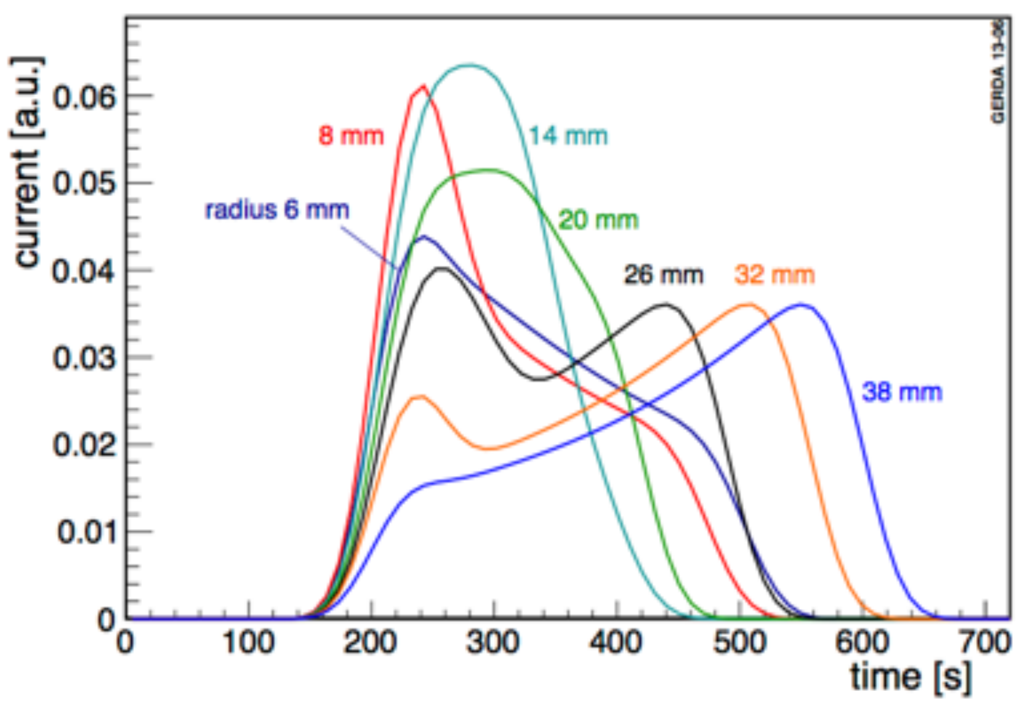
- K-42 decays on the surface of the HPGe detectors
- Nylon (BOREXINO) coated with TPB solution
- Transparent "Mini-Shroud" prevents K-42 ions drifting to the detector
- K-42 background reduced by > 10 fold

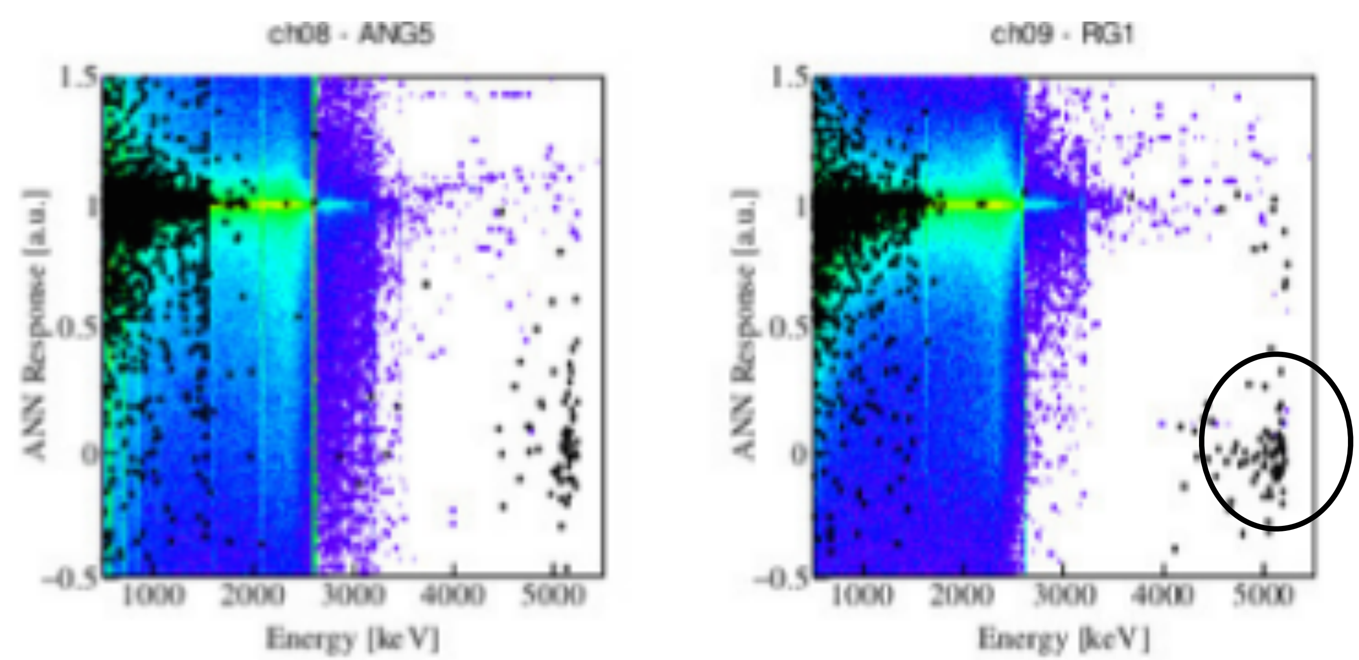


Pulse Shape Discrimination, Coax



- **Signal:** Single Site Event, **Background:** Multi-Site Ev.
  - PSD can veto Multi-Site Events in HPGe detector
- Neural network trained with calibration data
- Achieved performance is similar to Phase I
- Tuned to 90% acceptance of the DEP of 2.6 MeV line (Tl-208)





α's

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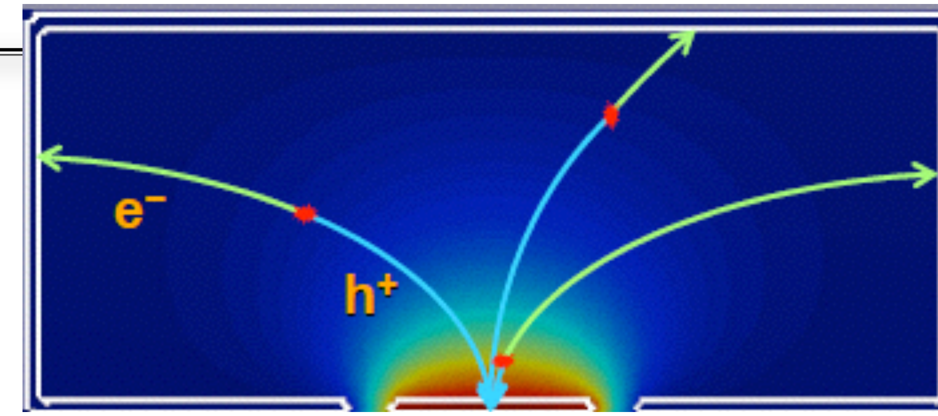
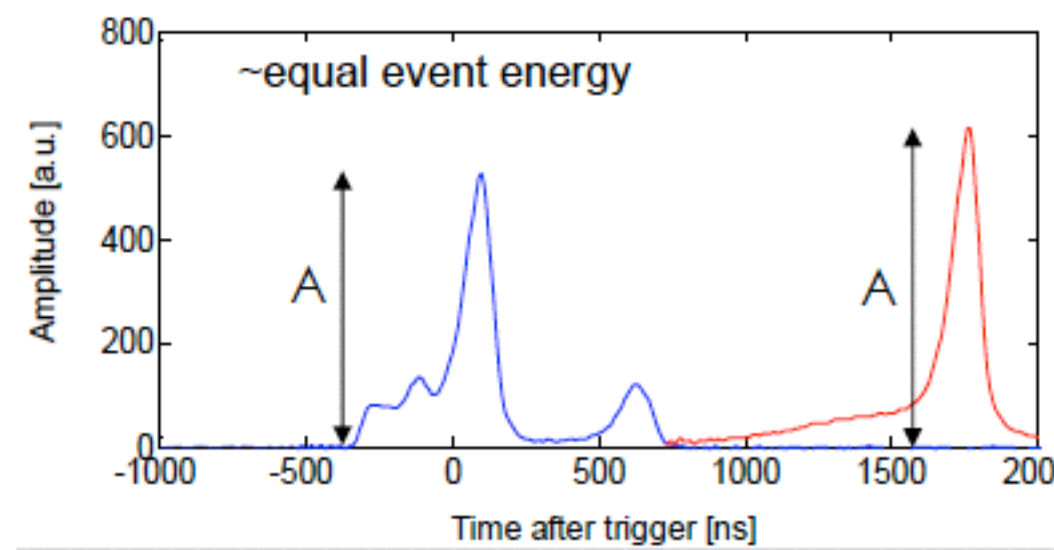
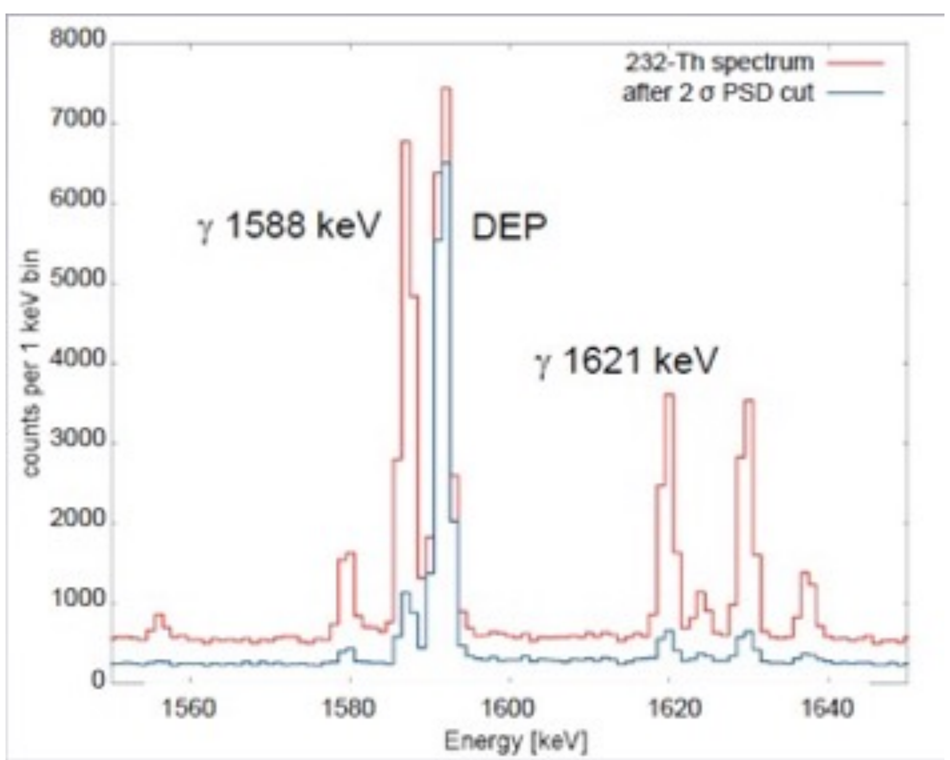
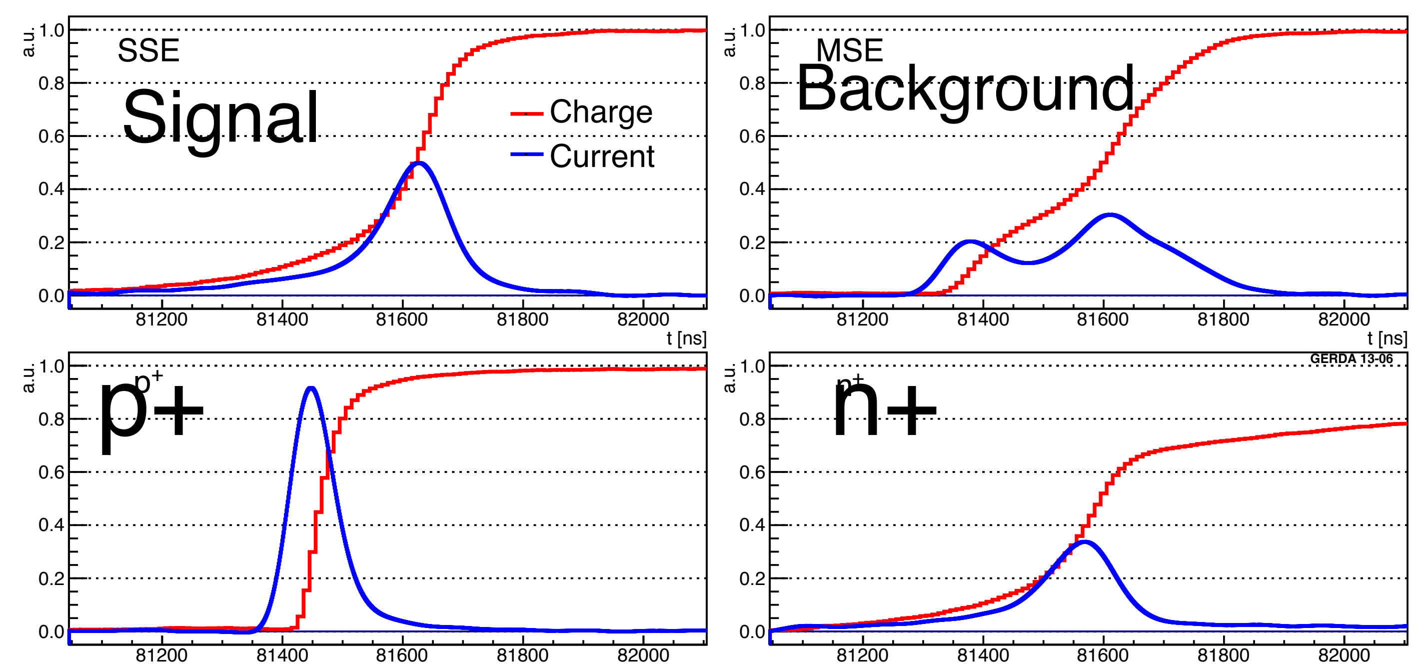
Pulse Shape Discrimination, BEGe

- BEGe detectors have a better PSD performance
- A/E single parameter cut is very efficient rejecting multisite events
- Tuned to 90% acceptance of the ^{208}Tl DEP peak
- ~85% acceptance for 2ν2β in the background data









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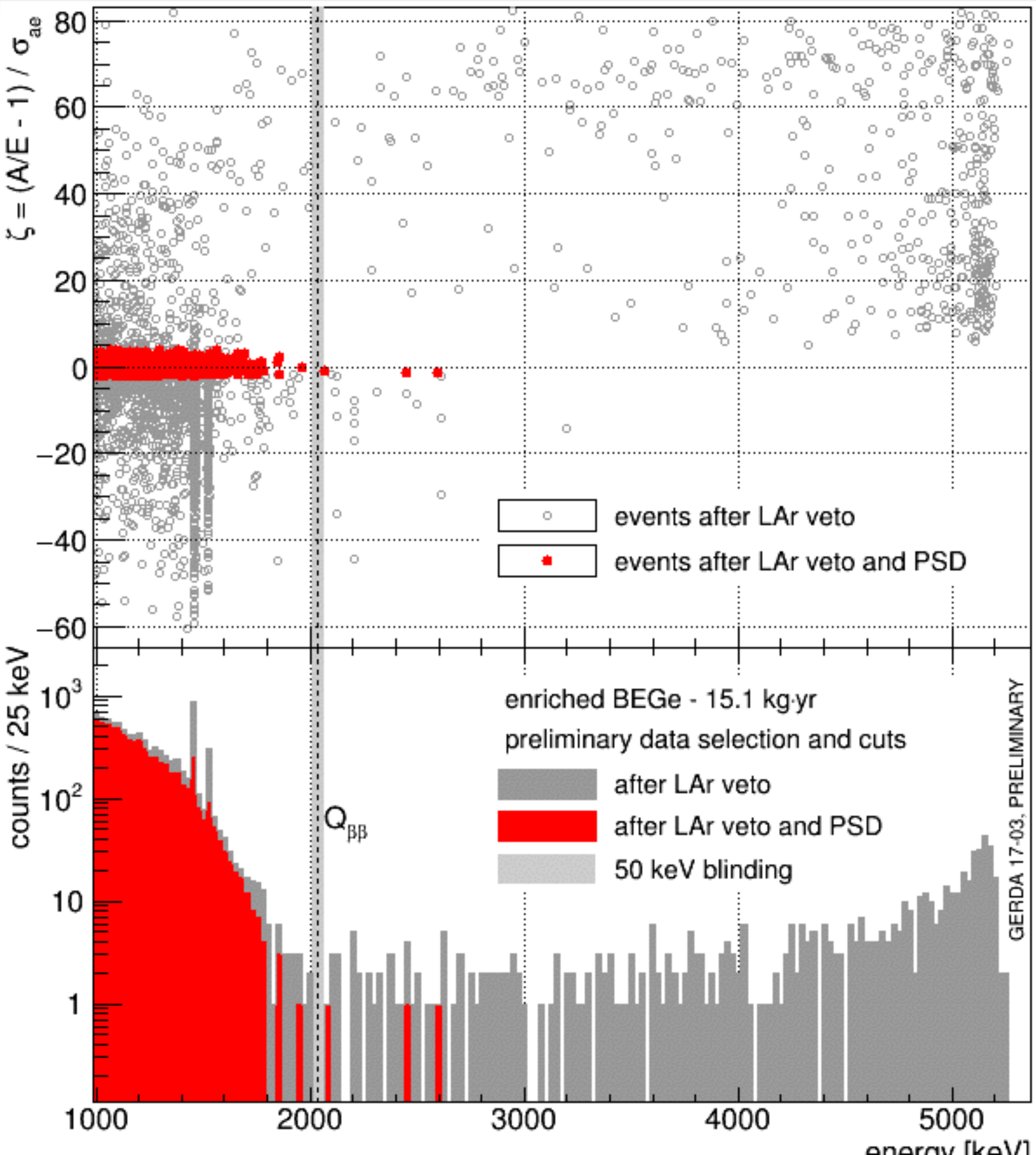
Pulse Shape Discrimination, BEGe



Highe A/E cut: surface alpha

signal band

gamma band: multisite events

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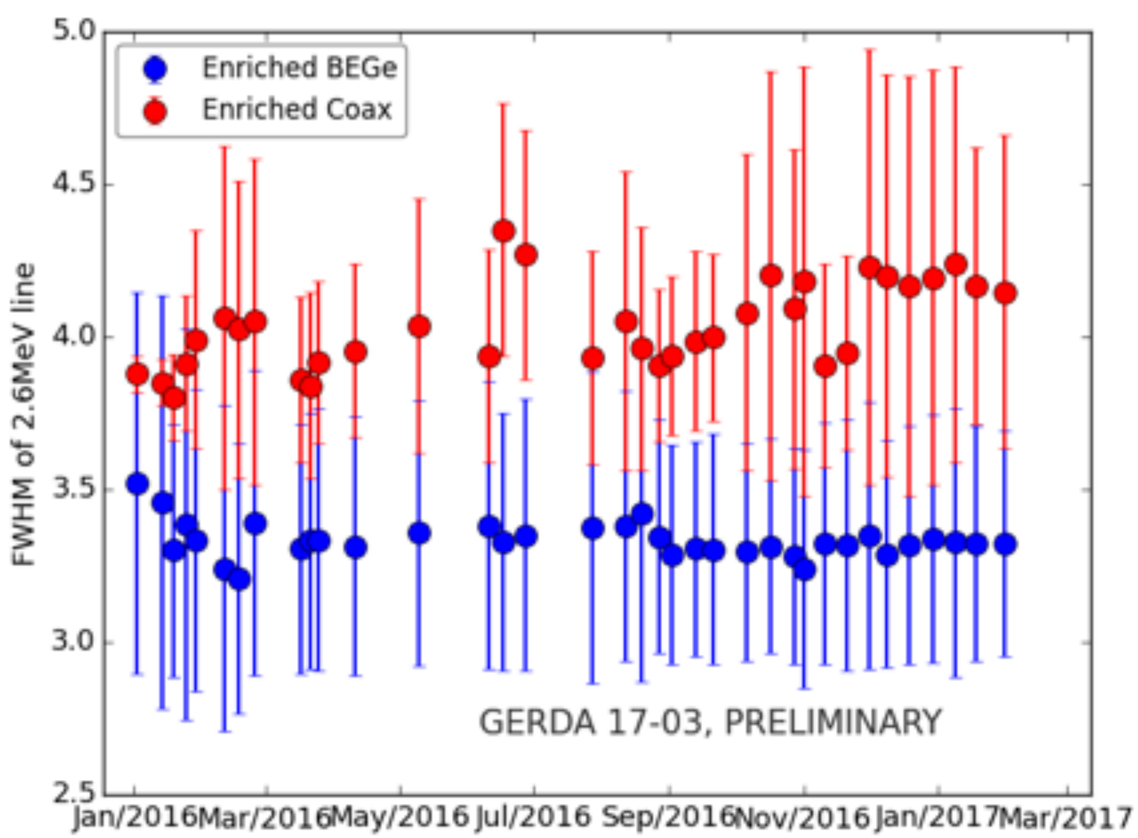
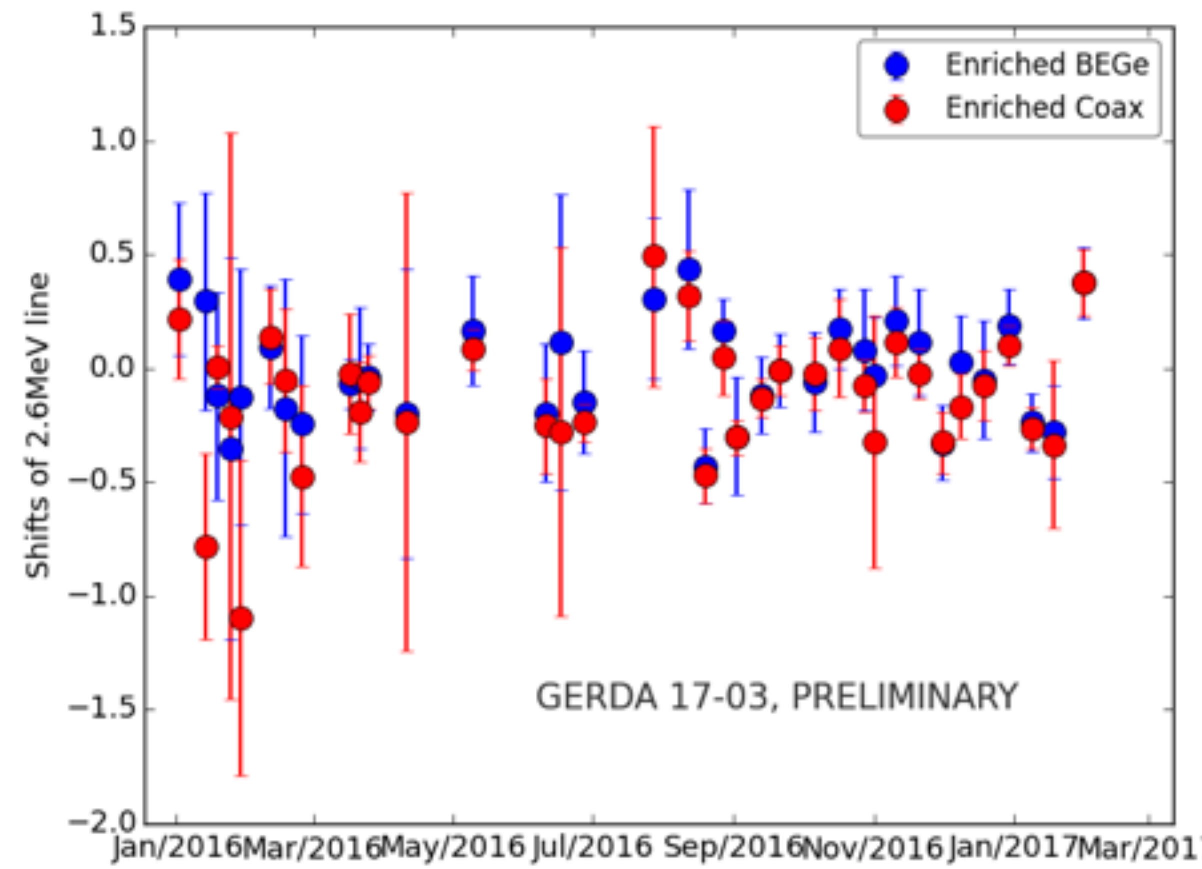
Phase II stability





- weakly calibration runs with Th-228 source
- Resolution at 2.6 MeV, BEGe: ~3.0 keV
- Resolution at 2.6 MeV, Coax.: ~4.0 keV
- Energy scale between calibrations stable within ±0.5 keV

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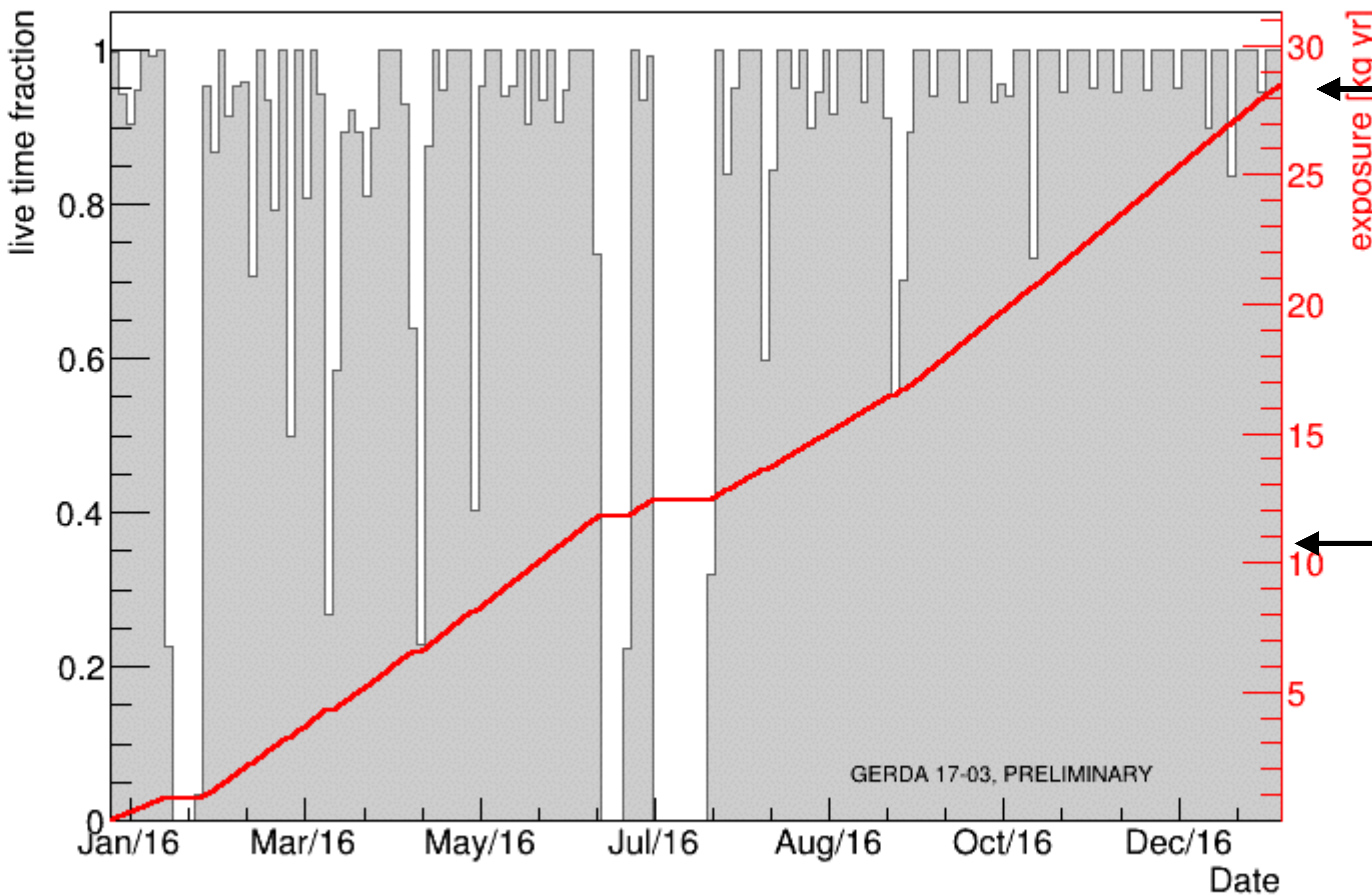
Phase II duty cycle



NuTel Venice 2017, March
28.5 kg Yr
just background
(no unblinding)

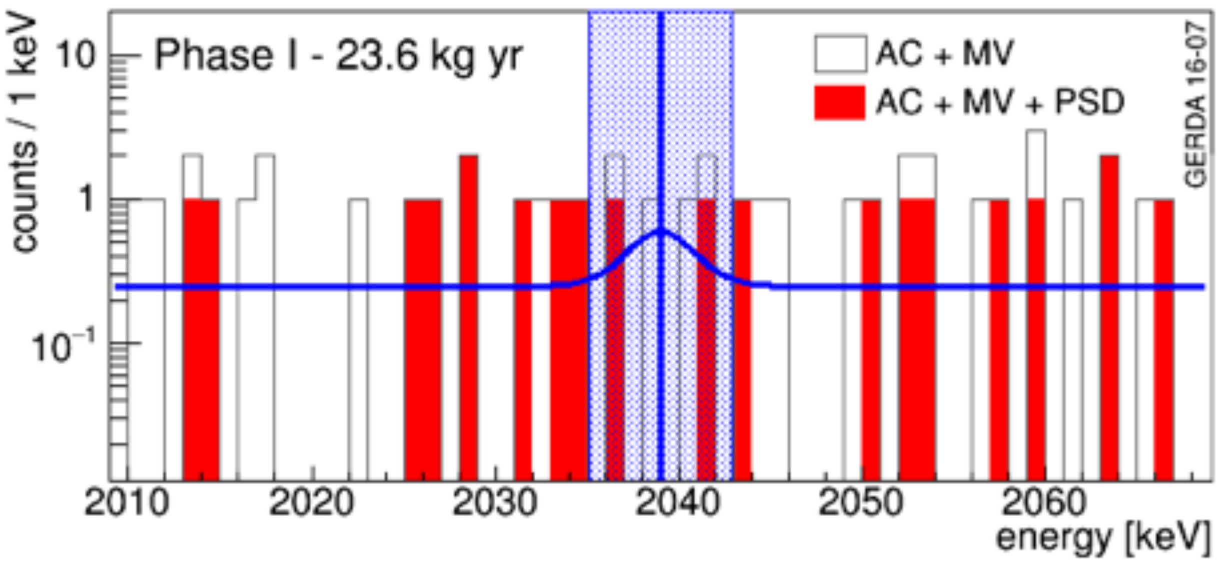
Neutrino 2016
10.8 kg Yr
Nature paper

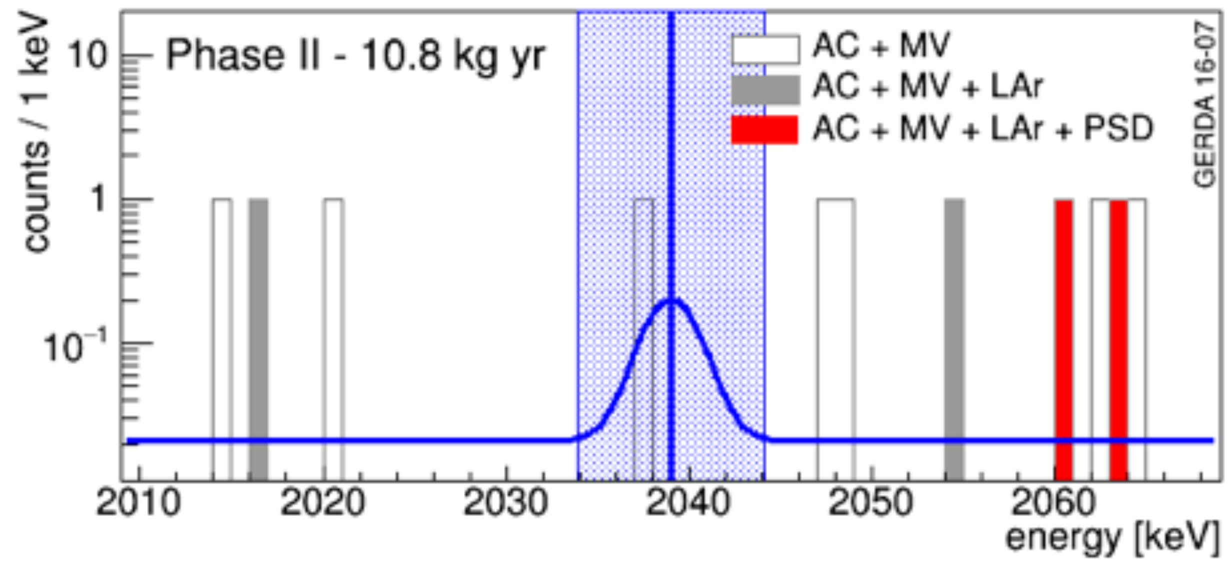
Phase II, 2016 results

data set	exposure [kg yr]	FWHM [keV]	efficiency	final background [10^{-3} cnt/(keV kg yr)]
PI golden	17.9	4.27±0.13	0.57±0.03	11±2
PI silver	1.3	4.27±0.13	0.57±0.03	30±10
PI BEGe	2.4	2.74±0.20	0.66±0.02	5^{+4}_{-3}
PI extra	1.9	4.17±0.19	0.58±0.04	4^{+5}_{-2}
PII coax	5.0	4.0±0.2	0.51±0.07	3^{+3}_{-1}
PII BEGe	5.8	3.0±0.2	0.60±0.02	$0.7^{+1.2}_{-0.5}$

- Exposure is calculated with total mass
- Efficiency includes: enrichment, active volume, 0νββ signal efficiency, PSD efficiency, LAr-veto dead time
- GERDA Phase II reached it's background goal !

Phase II, 2016 results





	profile likelihood 2-side test stat.	Bayesian flat prior on cts.
$0\nu\beta\beta$ cts. best fit value	0	0
$T_{1/2}(0\nu\beta\beta)$ lower limit [10^{25} yr]	> 5.3 (90% CL)	>3.5 (90% CI)
$T_{1/2}(0\nu\beta\beta)$ median sensitivity [10^{25} yr]	> 4.0 (90% CL)	>3.0(90% CI)

- Unbined profile likelihood: flat background + Gaussian signal

Phase II, 2016 results

nature International weekly journal of science

NATURE | ARTICLE

日本語要約

Background-free search for neutrinoless double-β decay of ^{76}Ge with GERDA

M. Agostini, M. Allardt, A. M. Bakalyarov, M. Balata, I. Barabanov, L. Baudis, C. Bauer, E. Bellotti, S. Belogurov, S. T. Belyaev, G. Benato, A. Bettini, L. Bezrukov, T. Bode, D. Borowicz, V. Brudanin, R. Brugnera, A. Caldwell, C. Cattadori, A. Chernogorov, V. D'Andrea, E. V. Demidova, N. Di Marco, A. di Vacri, A. Domula + *et al.*

Affiliations | Contributions

Nature **544**, 47–52 (06 April 2017) | doi:10.1038/nature21717
Received 22 November 2016 | Accepted 19 February 2017 | Published online 05 April 2017

Editor's summary العربية

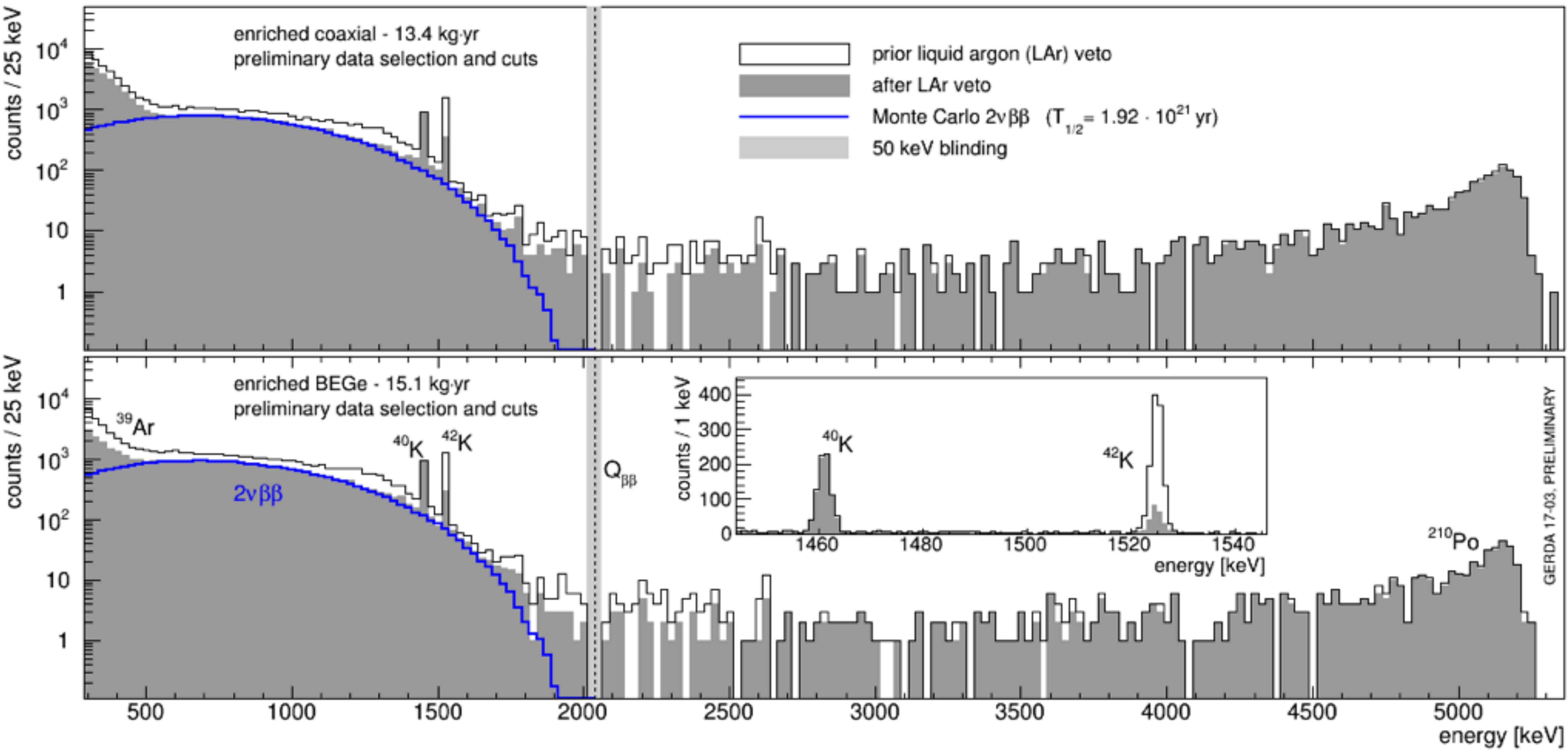
The nature of neutrinos is one of the most puzzling aspects of particle physics. Most extensions of the Standard Model assume neutrinos to be their own antiparticles, known as Majorana fermions, in wh…

Associated links

News & Views
Particle physics: The search for no neutrinos
by Barbeau

Background after 28.5 kg Yr

After LAr cut



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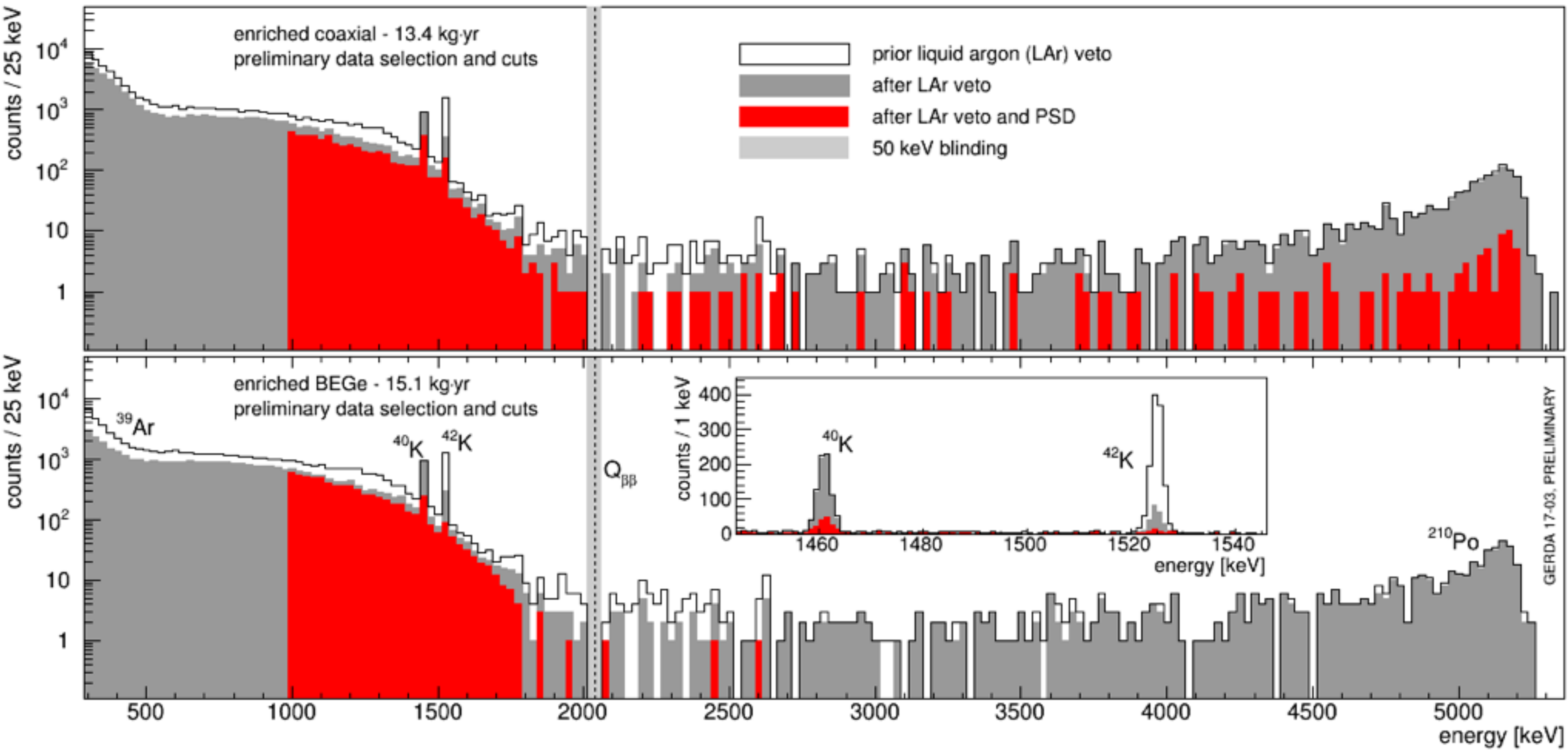
Background after 28.5 kg Yr

After LAr & PSD cut

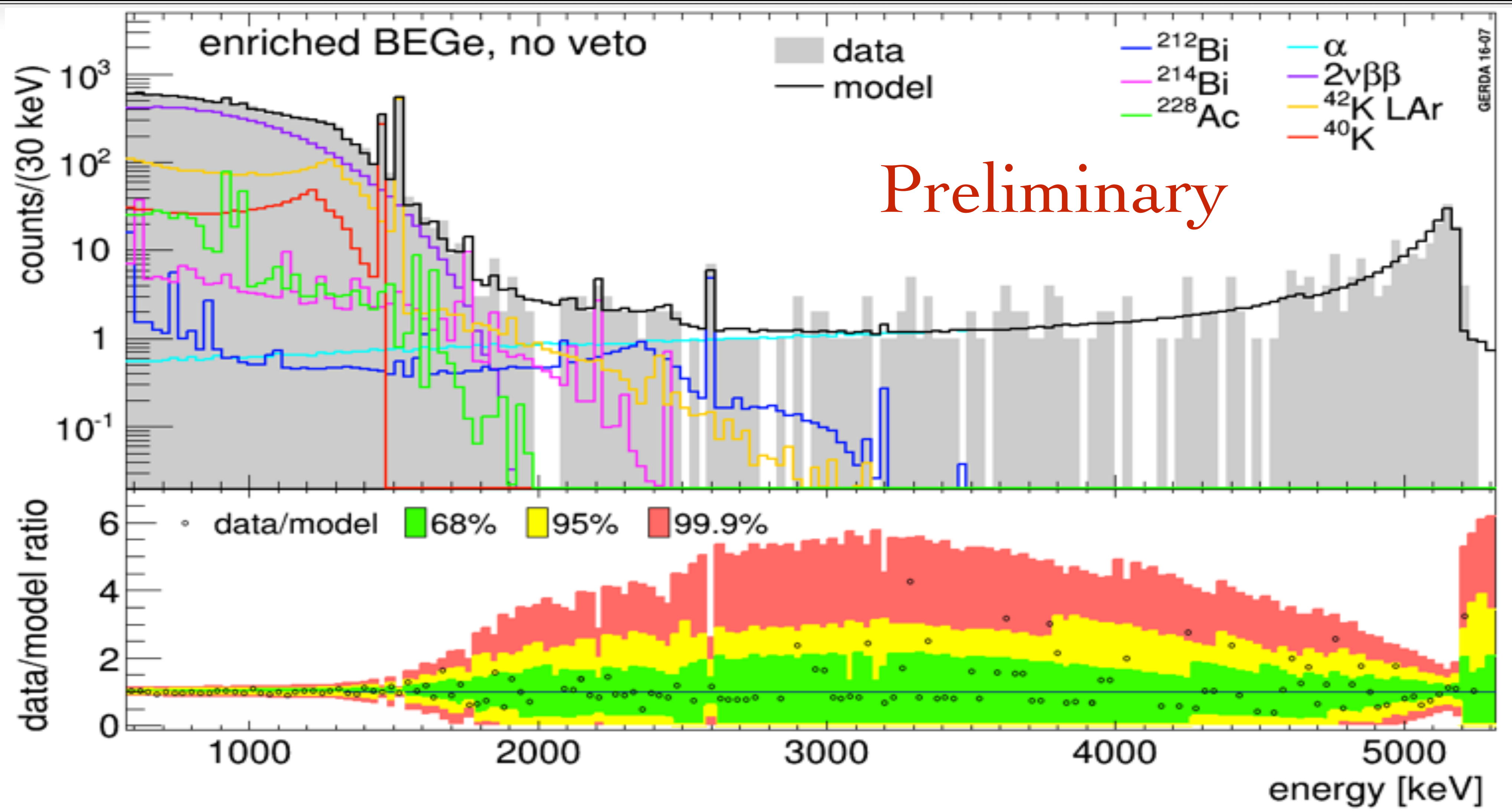


Phase II, 2017

- Background index from 2016 confirmed with 28.5 kg Yr exposure
- Next unblinding planed for June 2017
- GERDA Phase II is still background free !

	exposure $[\mathrm{kg \cdot yr}]$	BI* $\left[10^{-3} \cdot \frac{\mathrm{cts}}{\mathrm{keV \cdot kg \cdot yr}}\right]$	(cts)	…after LAr veto		…after PSD		…after LAr veto + PSD	
EnrBEGe	15.1	$12.3^{+2.3}_{-1.8}$	(38)	$3.9^{+1.3}_{-1.0}$	(12)	$3.2^{+1.2}_{-0.9}$	(10)	$\mathbf{0.6^{+0.6}_{-0.4}}$	(2)
EnrCoax	13.4	$16.7^{+2.7}_{-2.3}$	(46)	$8.0^{+1.9}_{-1.6}$	(22)	$8.0^{+1.9}_{-1.6}$	(22)	$\mathbf{2.2^{+1.1}_{-0.8}}$	(6)

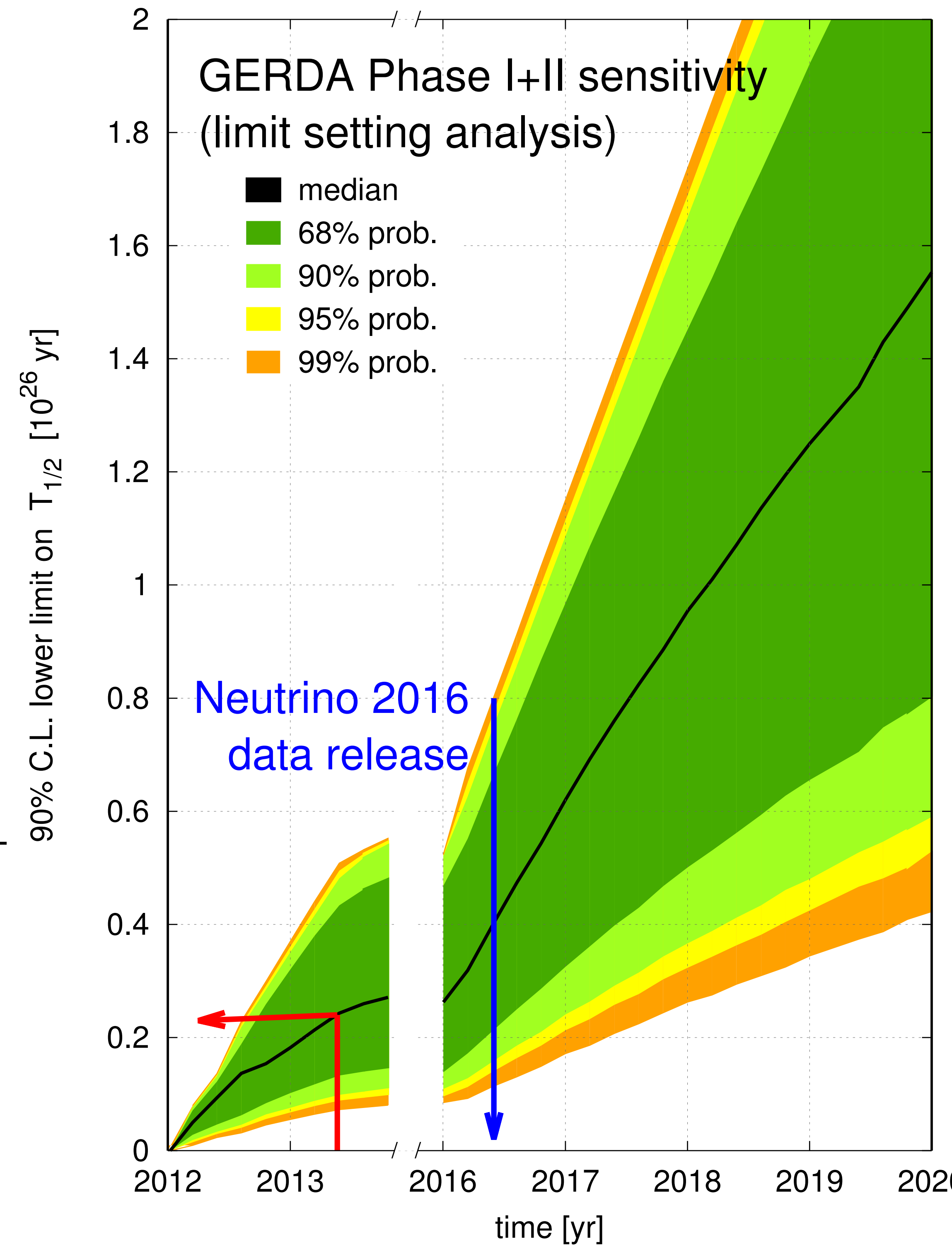
Background model



- Background reconstructed without PSD and LAr cut.
- Background around 2 MeV is explained by:
  - surface alphas
  - K-42 surface events
  - Bi-214 and Tl-208

Summary

- GERDA Phase II is taking data with 35.8 kg enriched germanium detectors
- Phase II background goal reached: running practically background free:
    - $0.6 \cdot 10^{-3}$ cts/(keV·kg·yr) achieved for BEGe data set
    - lowest background level in [cts/ROI] among all $0\nu\beta\beta$ experiments (10x lower than any running experiment)
- New $T_{1/2}$ limit: Phase II + Phase I published + Phase I extra:
    - Profile likelihood fit gives a median sensitivity of $4.0 \cdot 10^{25}$ yr
    - and a half life limit of $5.3 \cdot 10^{25}$ yr



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