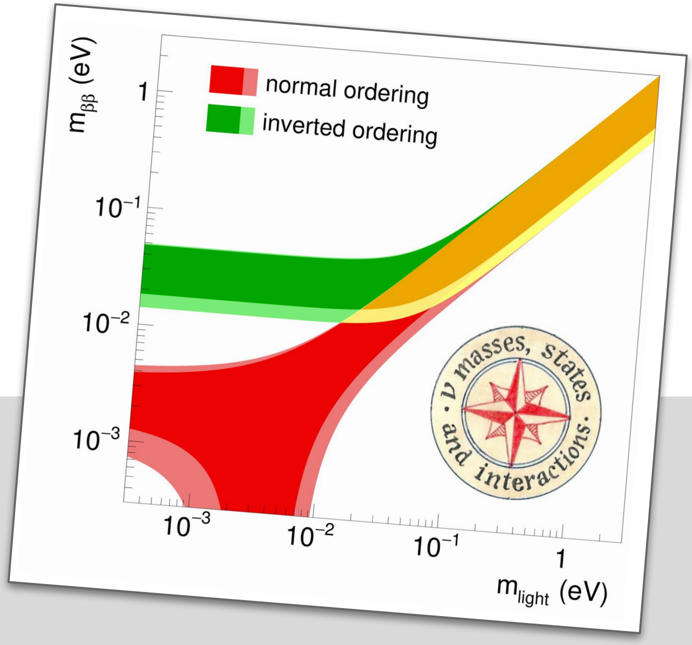
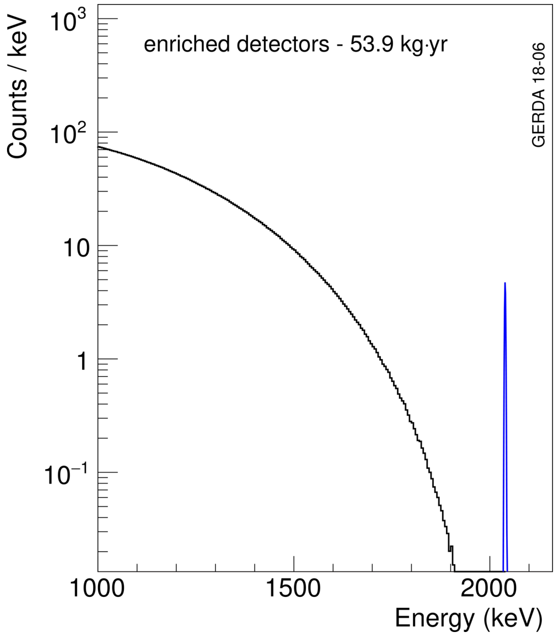
Recent results from GERDA Phase II

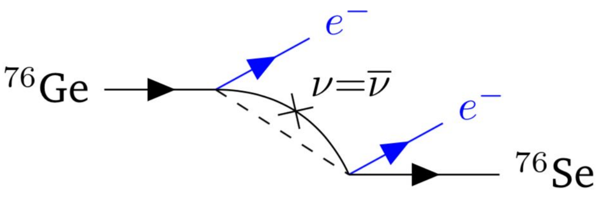


Christoph Wiesinger

Neutrino Oscillation Workshop, 14-Sep-2018

Search for 0νββ of ^{76}Ge





- **peak @ $Q_{\beta\beta}$ = 2039 keV** in summed electron spectrum

> physics beyond standard model ($\Delta L = 2$)

> **Majorana** mass

- **HPGe detectors** enriched in ^{76}Ge

> semiconductor
> -> **energy resolution O(0.1)% @ $Q_{\beta\beta}$**

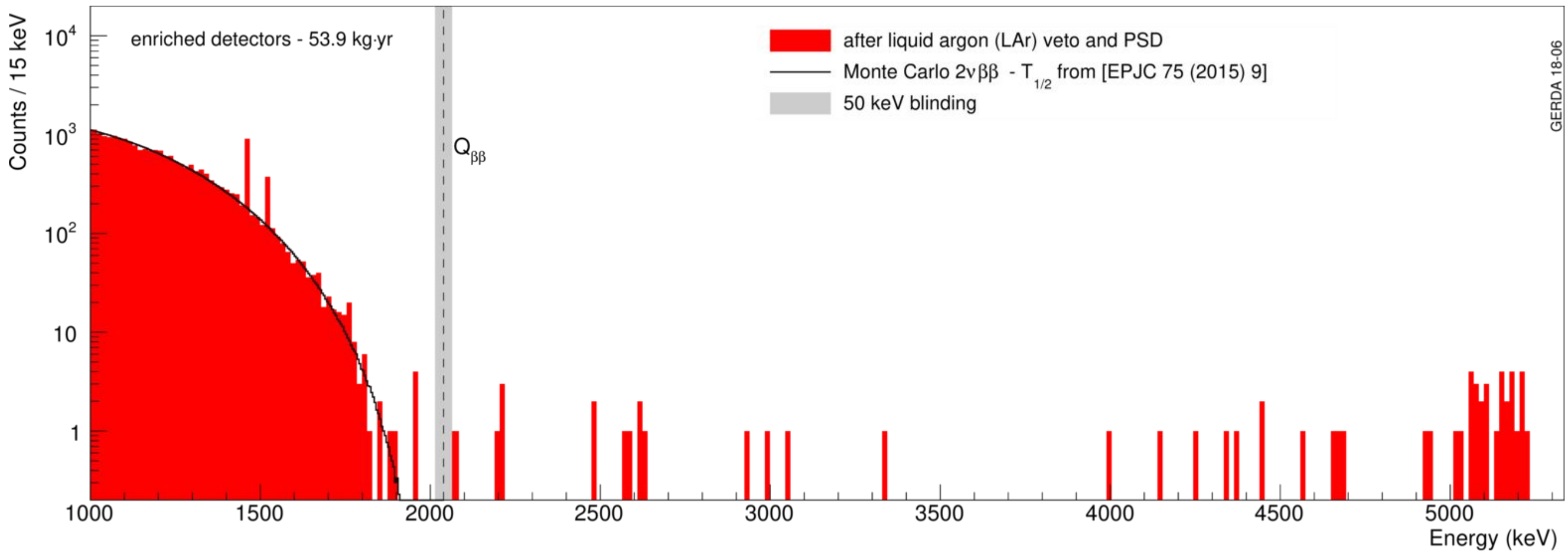
> high density
> -> e^- absorbed within O(1)mm

> source = detector
> -> high detection efficiency

> high purity
> -> no intrinsic background

[Astropart.Phys. 91 (2017) 15-21]

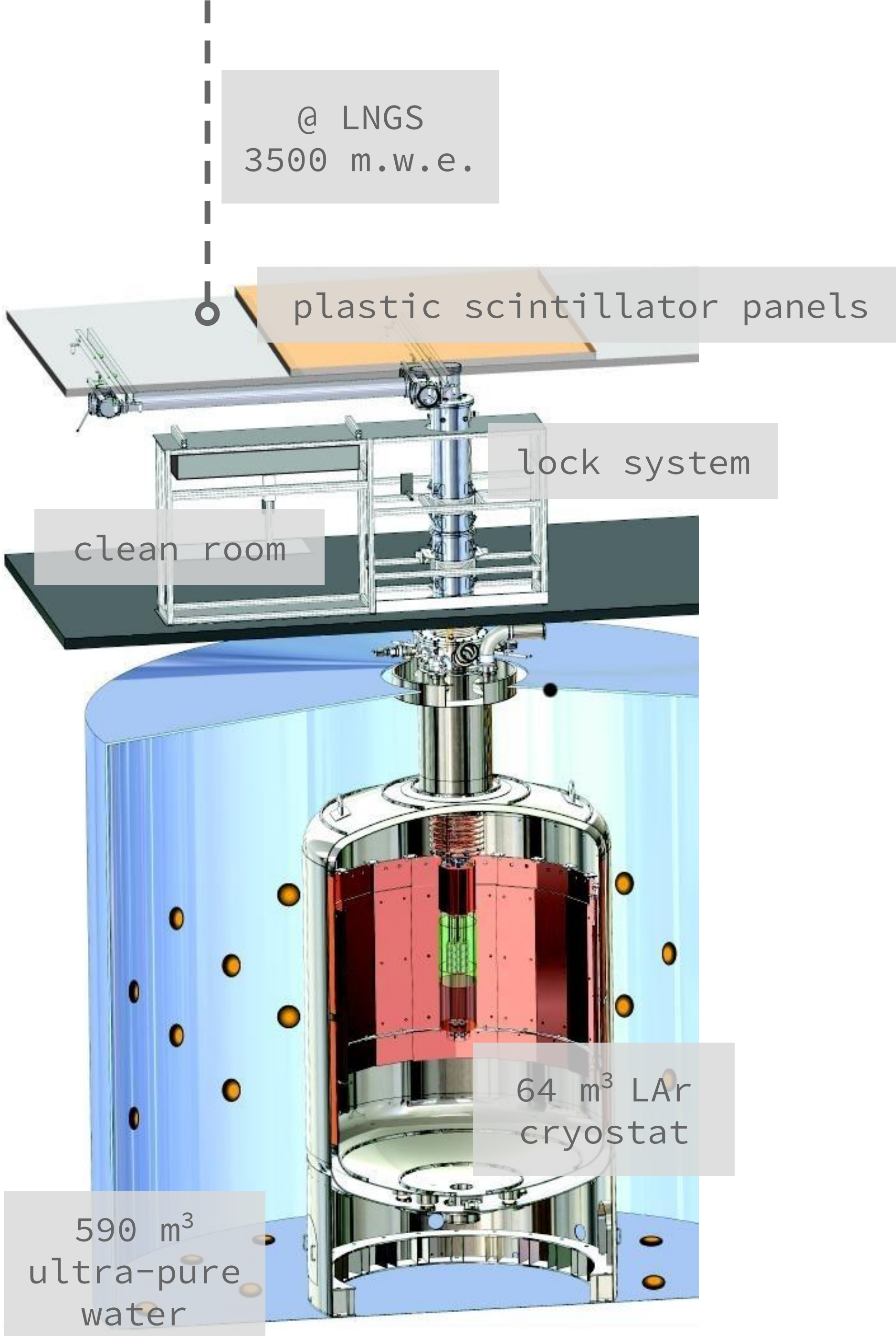
Search for 0νββ of ^{76}Ge with GERDA

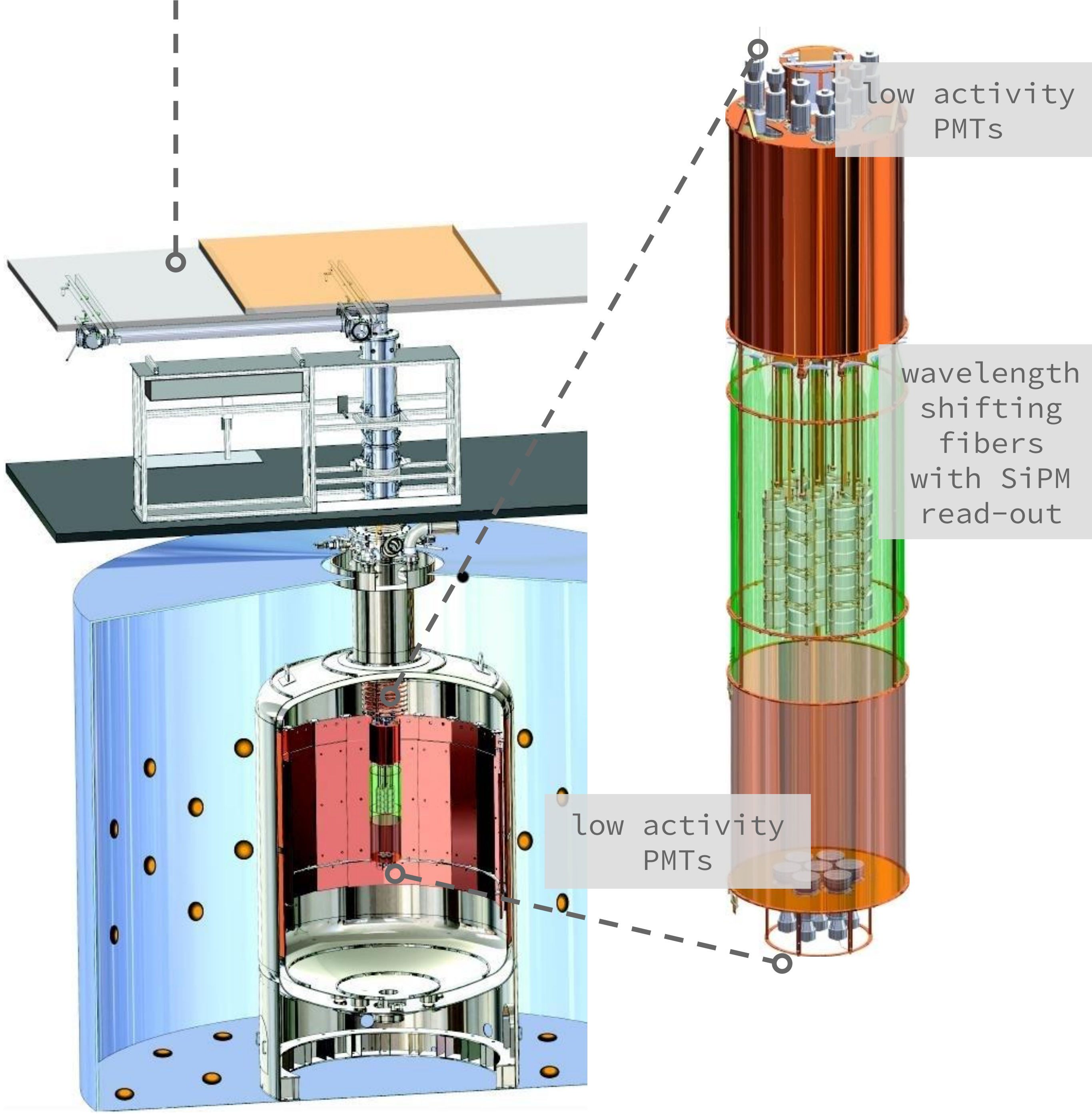


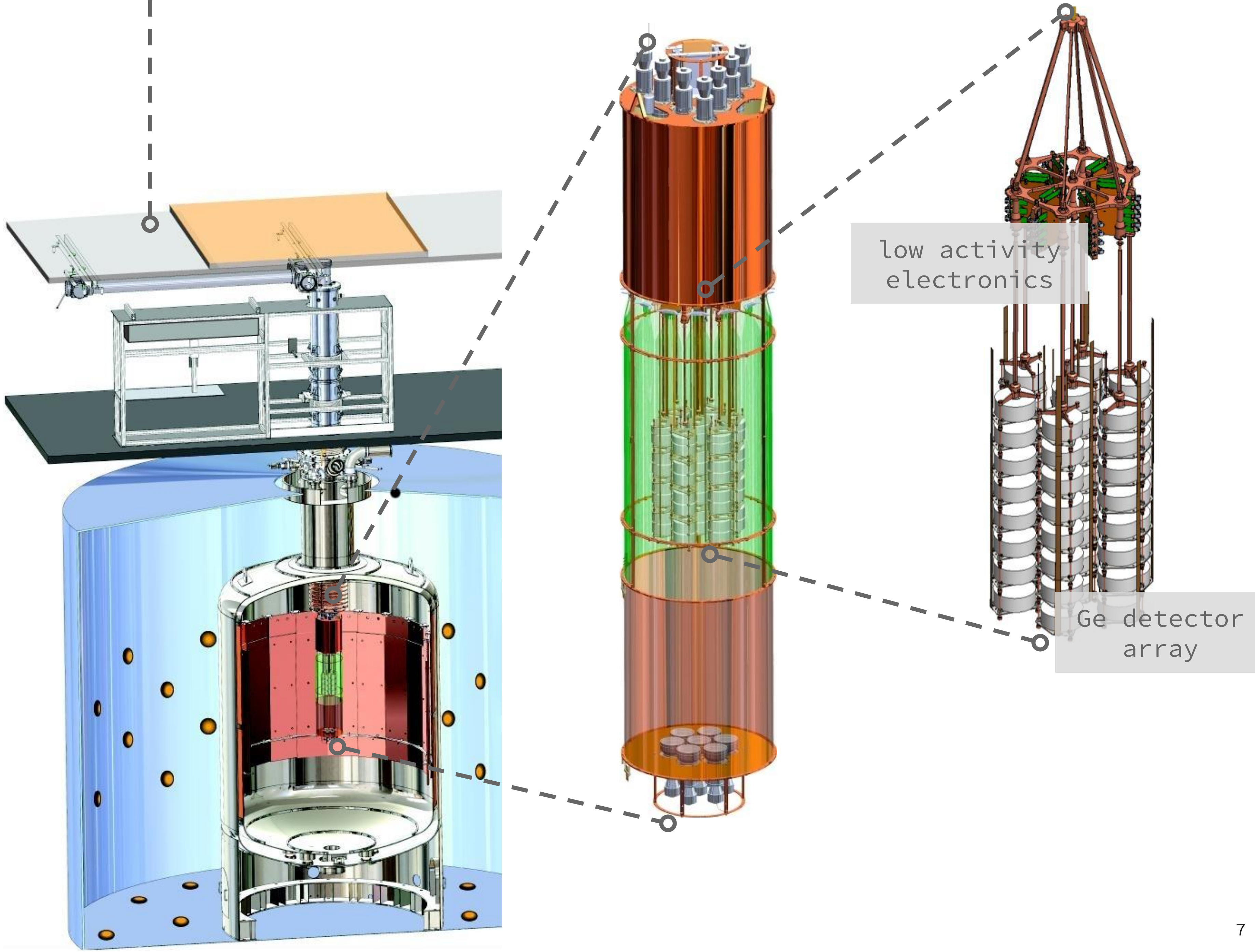
- data blinding @ $Q_{\beta\beta}$ ± 25 keV
- background expectation **< 0.2 cts** in $Q_{\beta\beta}$ ± 2σ

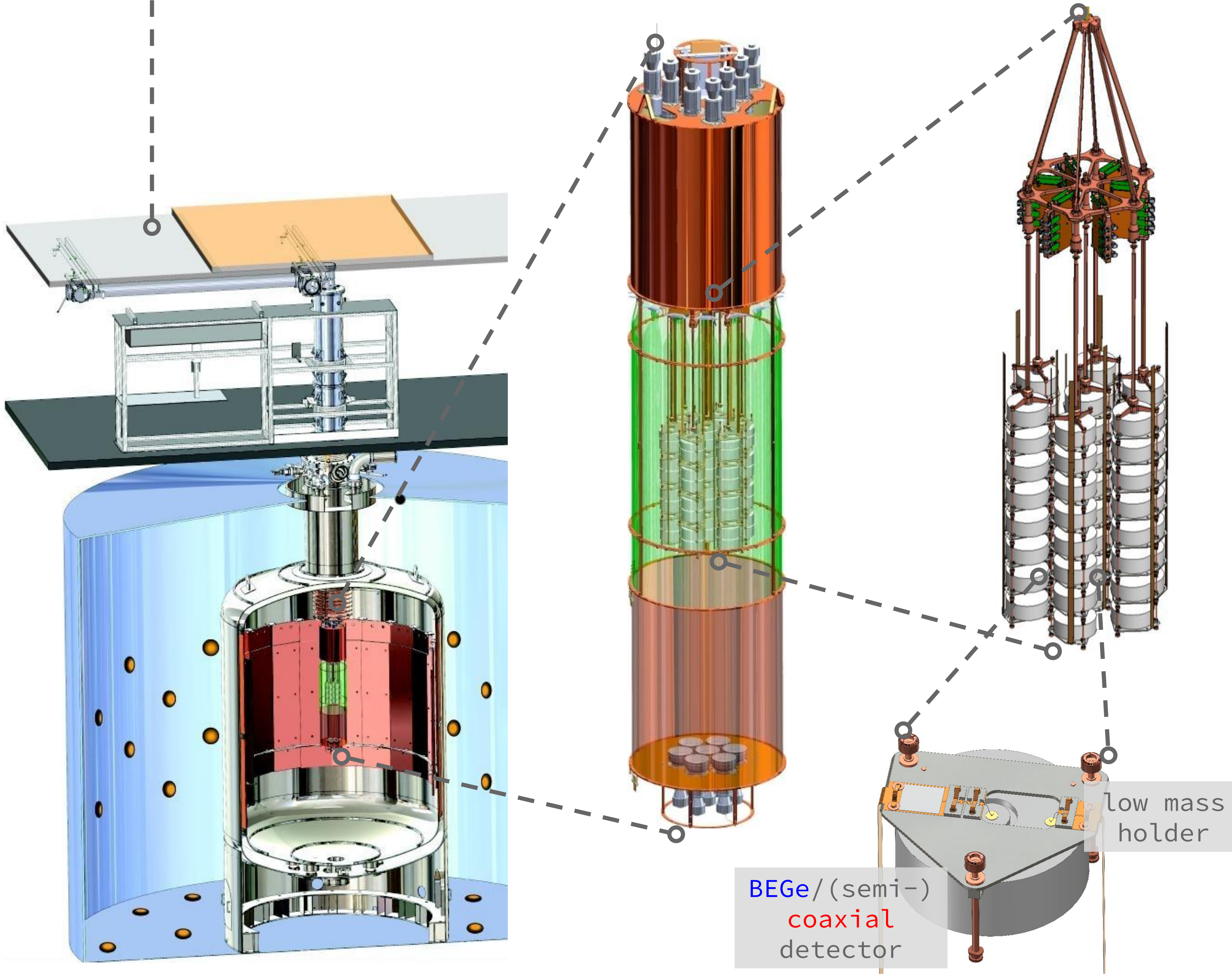
"high resolution background-free 0νββ search"

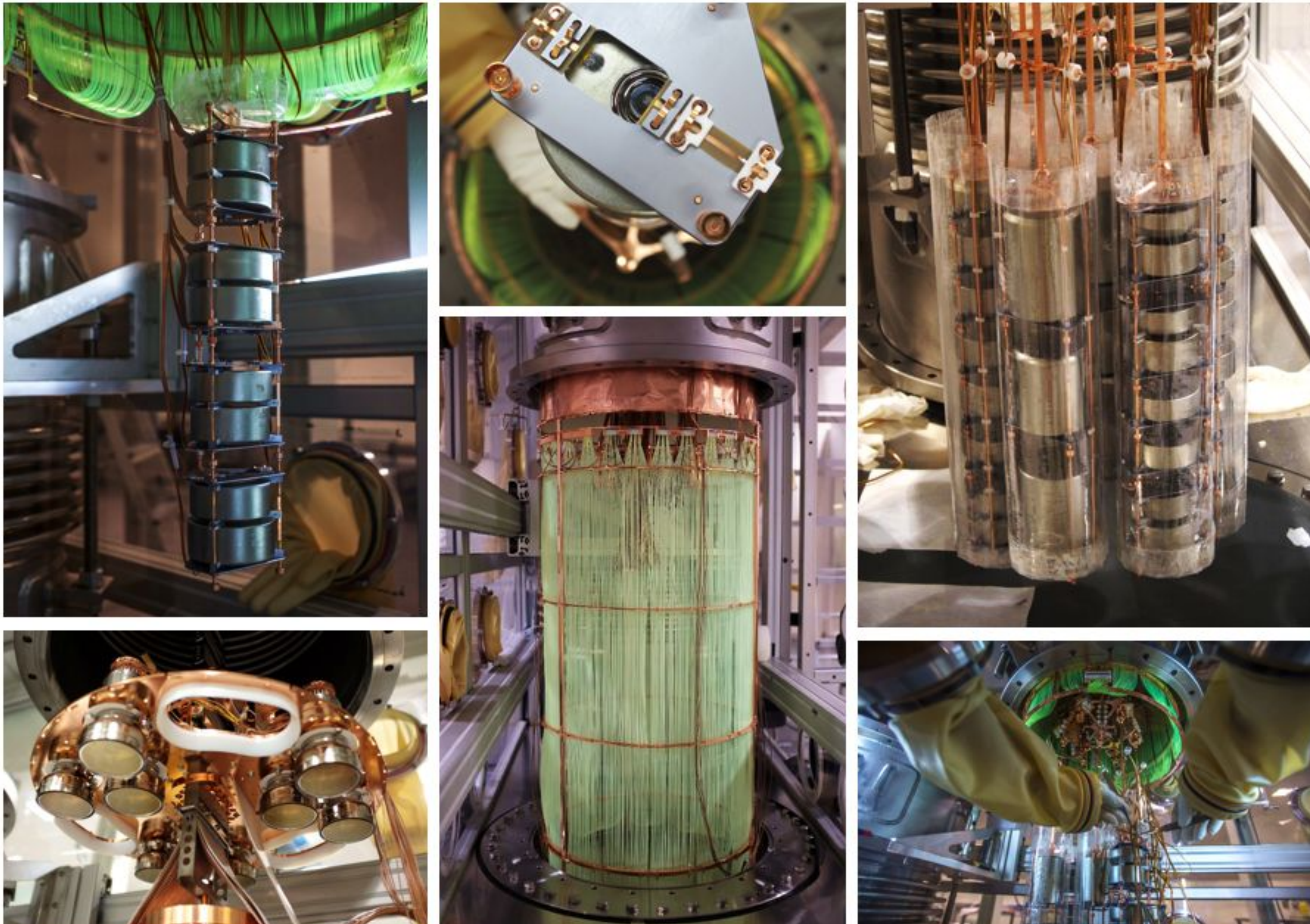
› GERDA Phase II


@ LNGS
3500 m.w.e.
plastic scintillator panels
lock system
clean room
64 m³ LAr
cryostat
590 m³
ultra-pure
water


low activity PMTs
wavelength shifting fibers with SiPM read-out
low activity PMTs


low activity
electronics
Ge detector
array


low mass holder
BEGe/(semi-) coaxial detector



GERDA Phase II

Phase II:

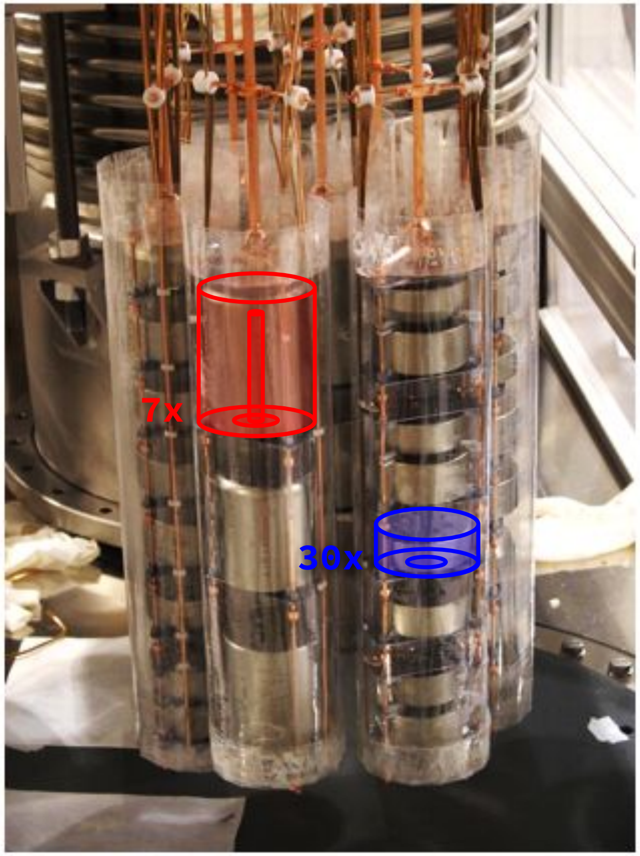
- 7 enriched (semi-)coaxial **(15.6 kg)**
- 30 enriched BEGe **(20.0 kg)**
- 3 natural semi-coaxial (7.6 kg)

Phase II upgrade:

- 5 enriched **inverted coaxial (9.5 kg)**

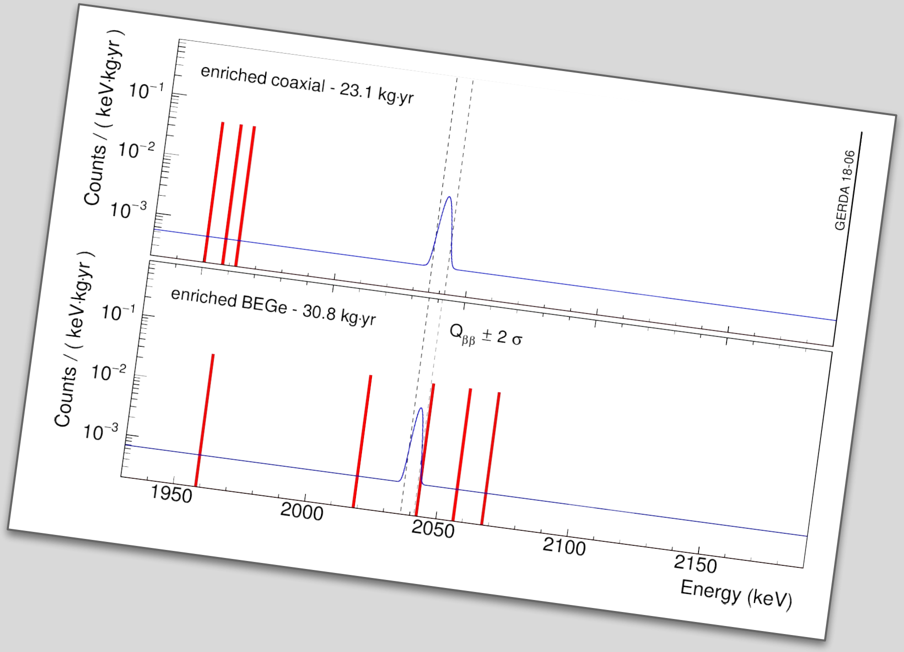
  \+ **new LAr veto** instrumentation

  \+ cleaner materials

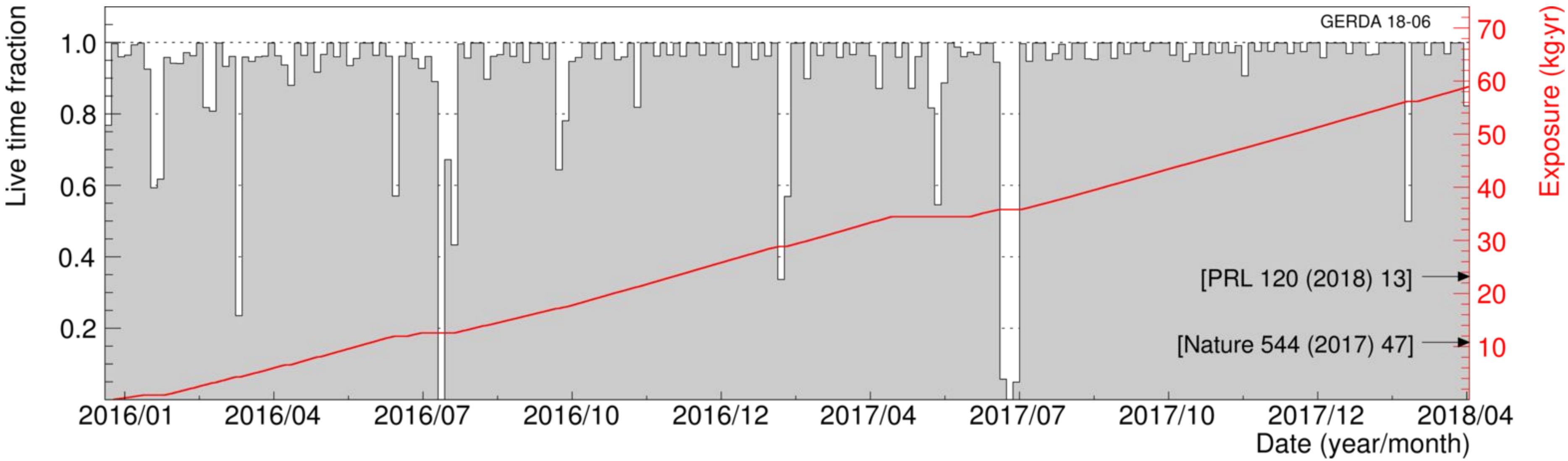


GERDA Phase II goals	
background	$\sim 10^{-3}$ cts/(keV·kg·yr)
exposure	$\gtrsim 100$ kg·yr
sensitivity	$T^{0\nu}_{1/2} \gtrsim 10^{26}$ yr

› RECENT RESULTS



Data taking / duty cycle



- from Dec-2015 to Apr-2018 -> **834.8 d** live time
- **92.9%** duty cycle, **80.4%** data quality

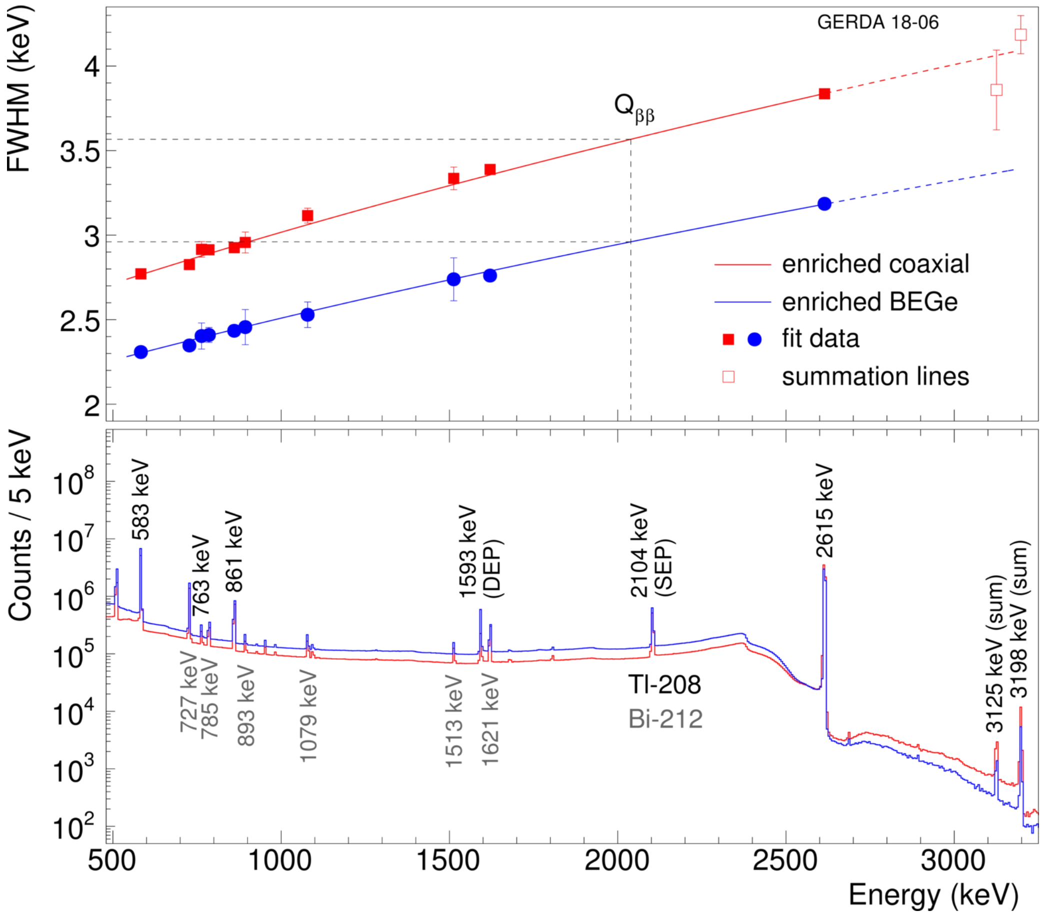
> **58.9 kg·yr** (82.4 kg·yr with Phase I)

“largest ^{76}Ge exposure ever achieved”

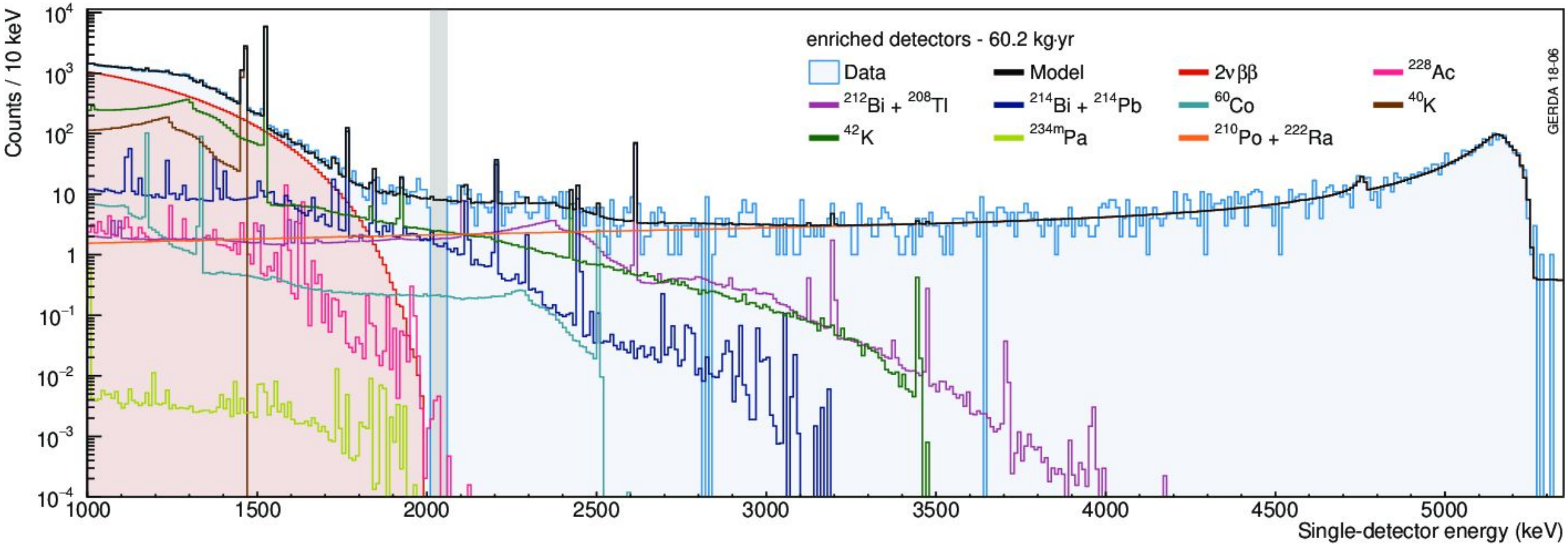
Energy reconstruction / resolution

- weekly calibrations with **^{228}Th**
- every 20 s **test pulse** injection for gain stability measurement
- "zero area cusp" (**ZAC**) filter
  [Eur. Phys. J. C75 (2015) 255]

	FWHM @ $Q_{\beta\beta}$
coaxials	**3.6(1) keV**
BEGe	**3.0(1) keV**



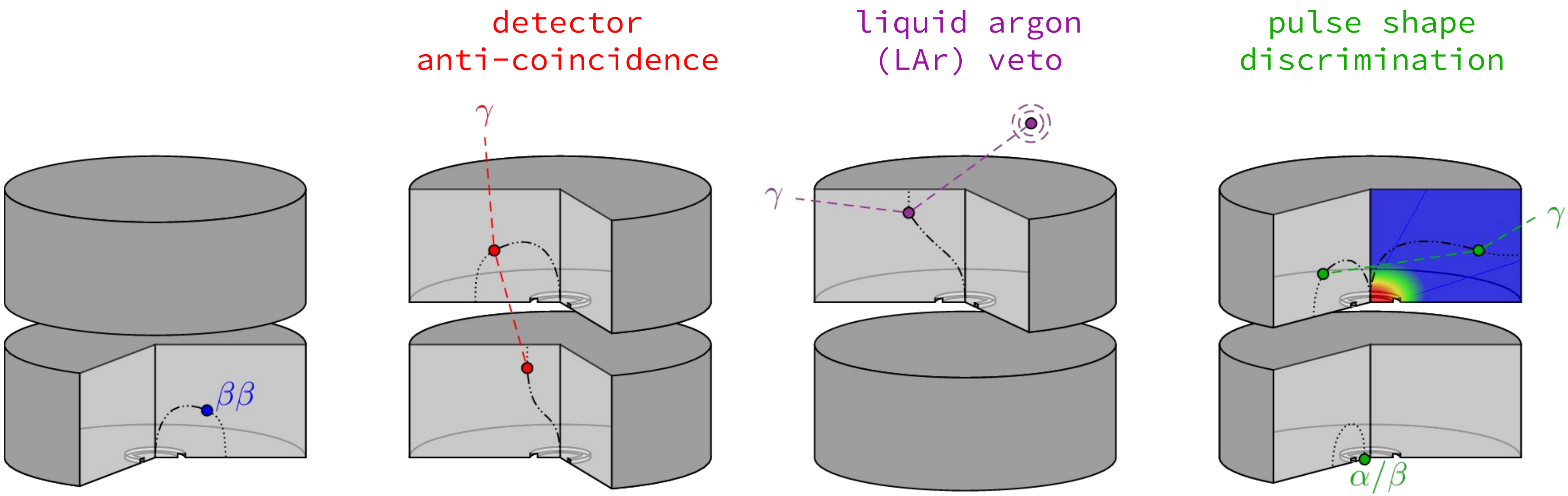
Background model



- full GERDA setup is reproduced in GEANT4
- **Bayesian fit** of multiple datasets (BEGe, coaxial, multiplicity=2, $^{40}K/^{42}K$ tracking) with Monte Carlo PDFs, **screening measurements** as priors

> α from **$^{210}Po/(^{222}Ra)$**, β from **^{42}K**, γ from **$^{208}Tl/^{214}Bi$**

Active background suppression



differentiate **point like** (single site) **ββ** topology from:

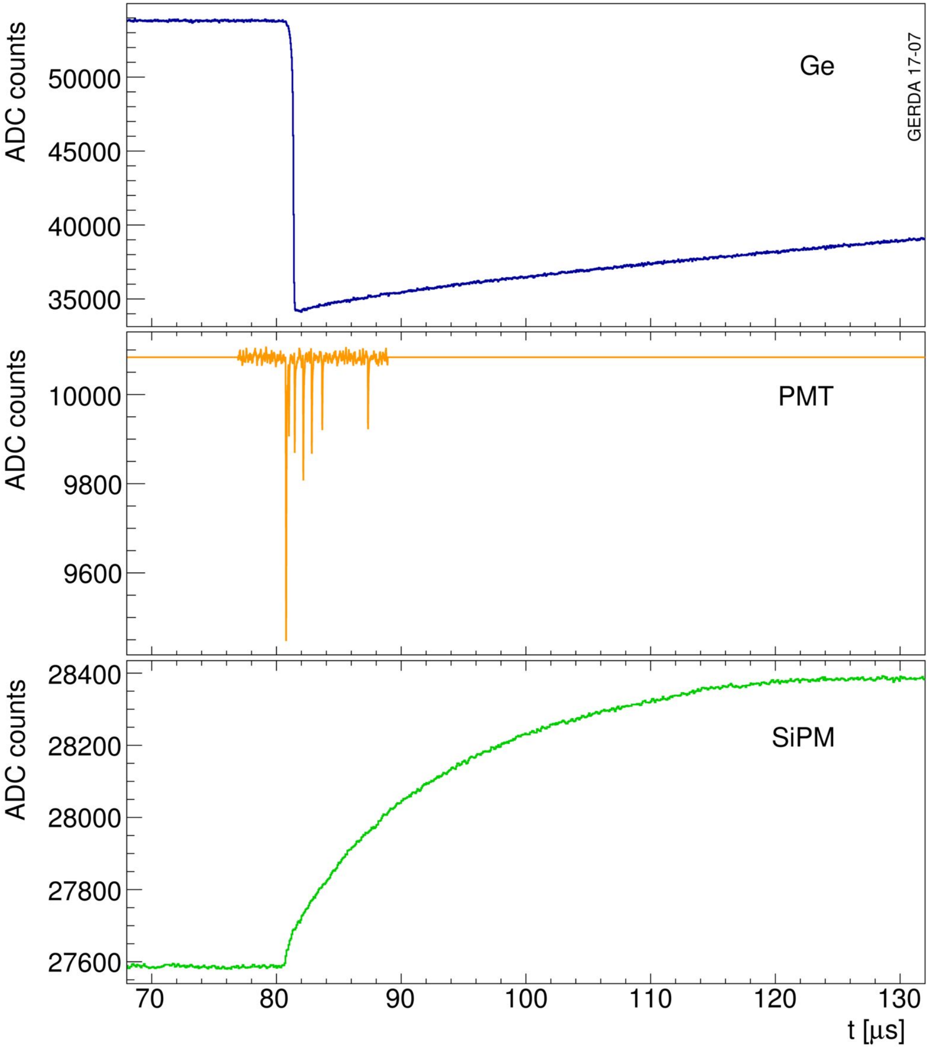
- **multi-detector** interactions
- interactions with **coincident energy deposition** in surroundings
- **multi-site/surface** interactions

LAr Veto

- channelwise (PMT/SiPM) **anti-coincidence** condition
- thresholds at ~0.5 P.E.
- acceptance determined from random triggers

	$0\nu\beta\beta$ acceptance
Phase II	**97.7(1) %**

- **Compton suppression** by LAr veto -> *almost pure* **$2\nu\beta\beta$ continuum**



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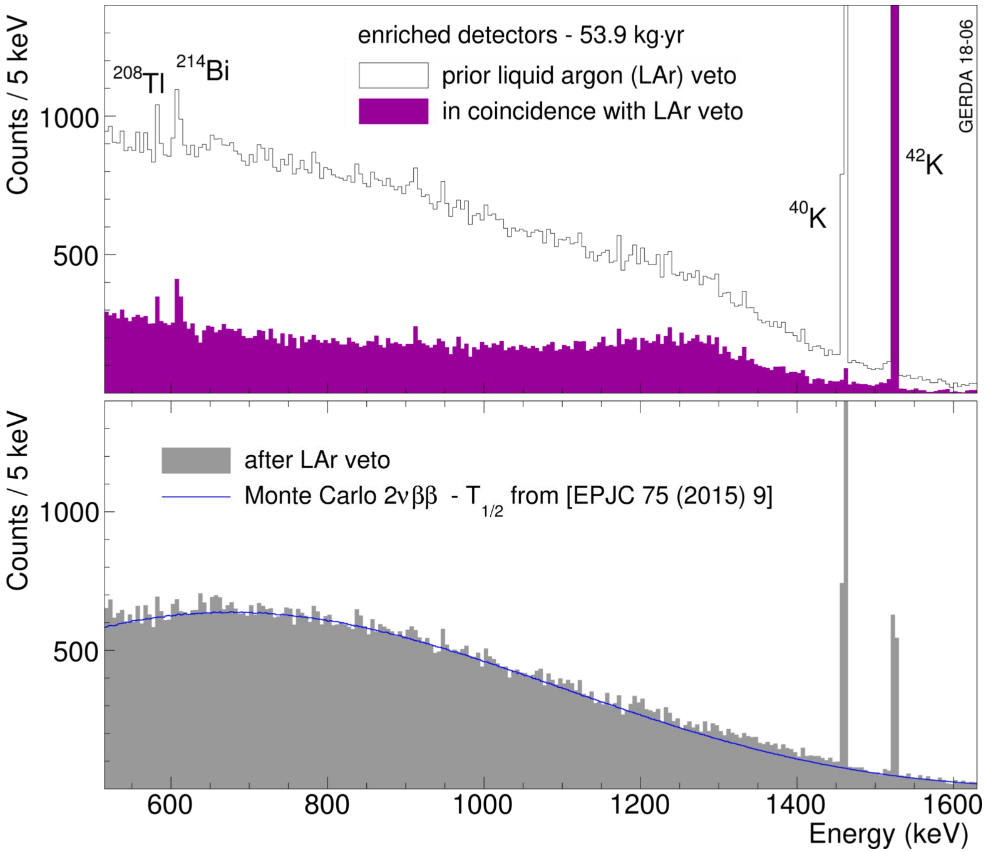
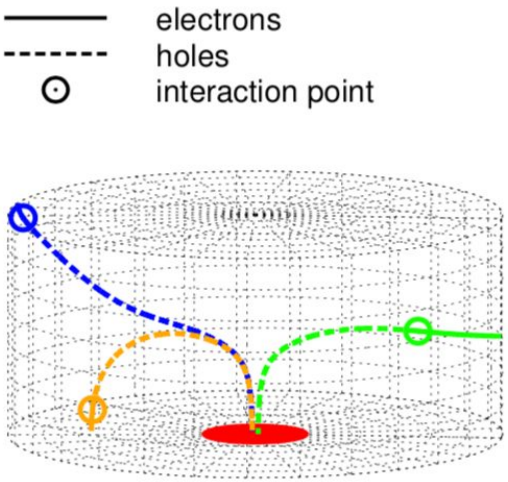
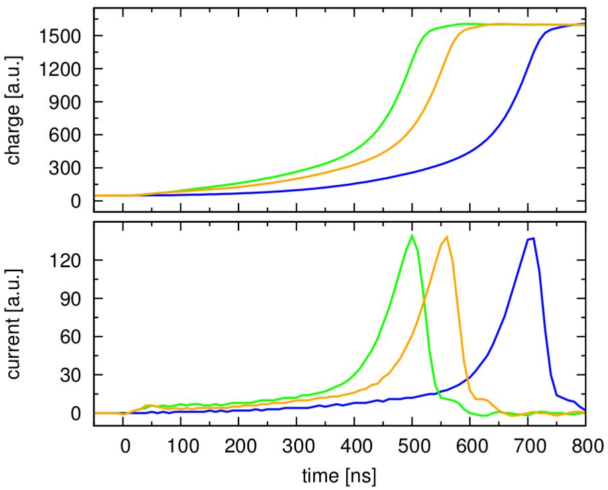


Pulse shape discrimination for BEGe's

- mono-parametric cut based on current pulse amplitude A and total energy E **(A/E)**
  [Eur. Phys. J. C73 (2013) 2583]
- normalized to single-site events
- cut value determined from **calibration data**
  (low cut @ 90% DEP acceptance, high cut @ 4σ)

	$0\nu\beta\beta$ acceptance
BEGe	**(87.6±2.5)%**





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	0νββ acceptance
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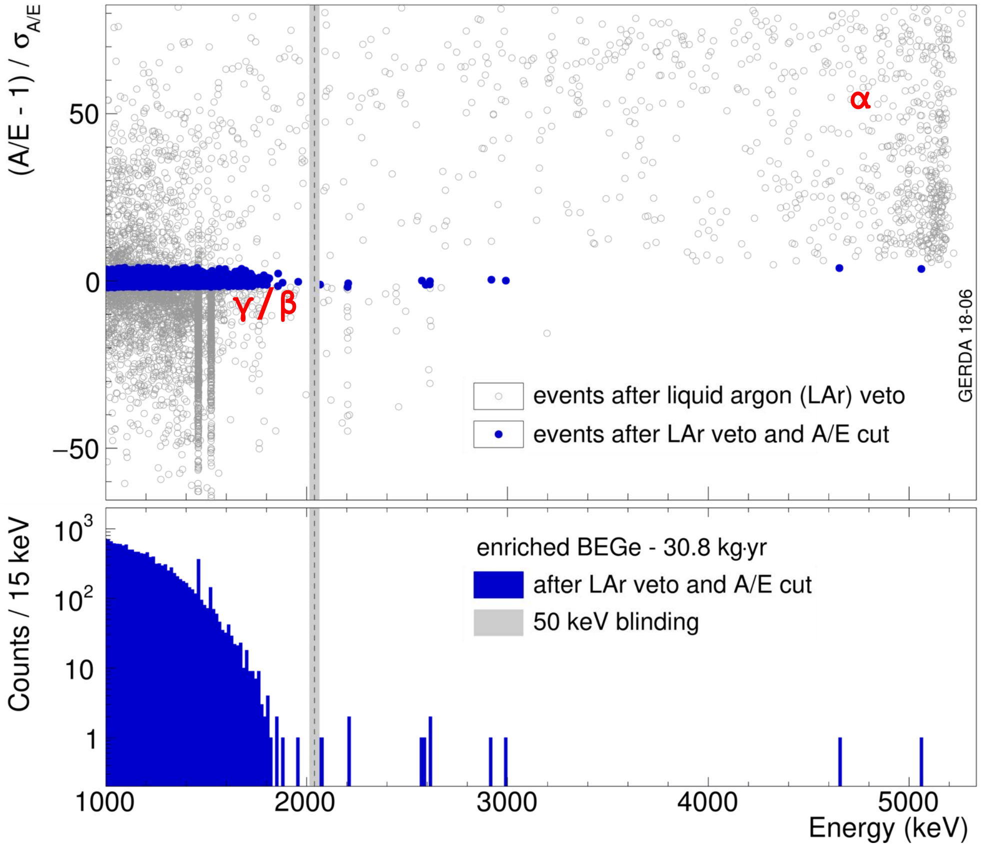
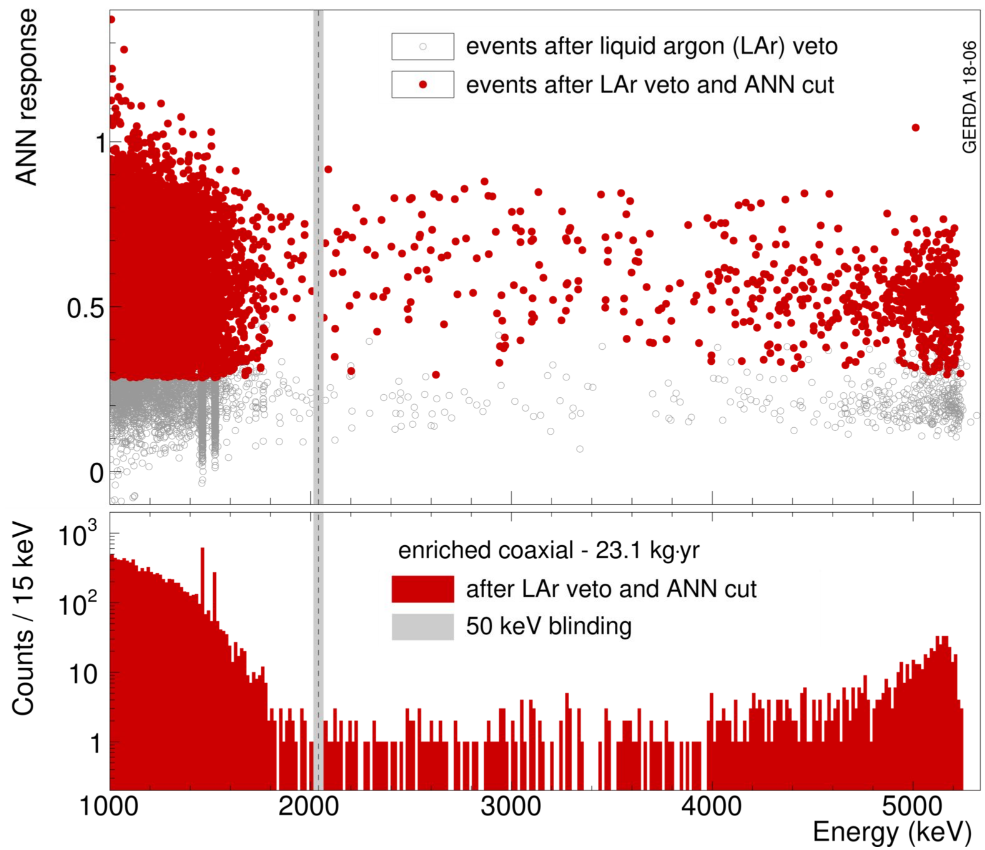


Pulse shape discrimination for Coaxials

- artificial neural network **(ANN)** trained on ^{208}Tl DEP (signal) and ^{212}Bi SEP (background)
- acceptance from pulse shape simulations, cross-checked with $2\nu\beta\beta$ events

	$0\nu\beta\beta$ acceptance
coaxials	**(84±5)%**



Pulse shape discrimination for Coaxials

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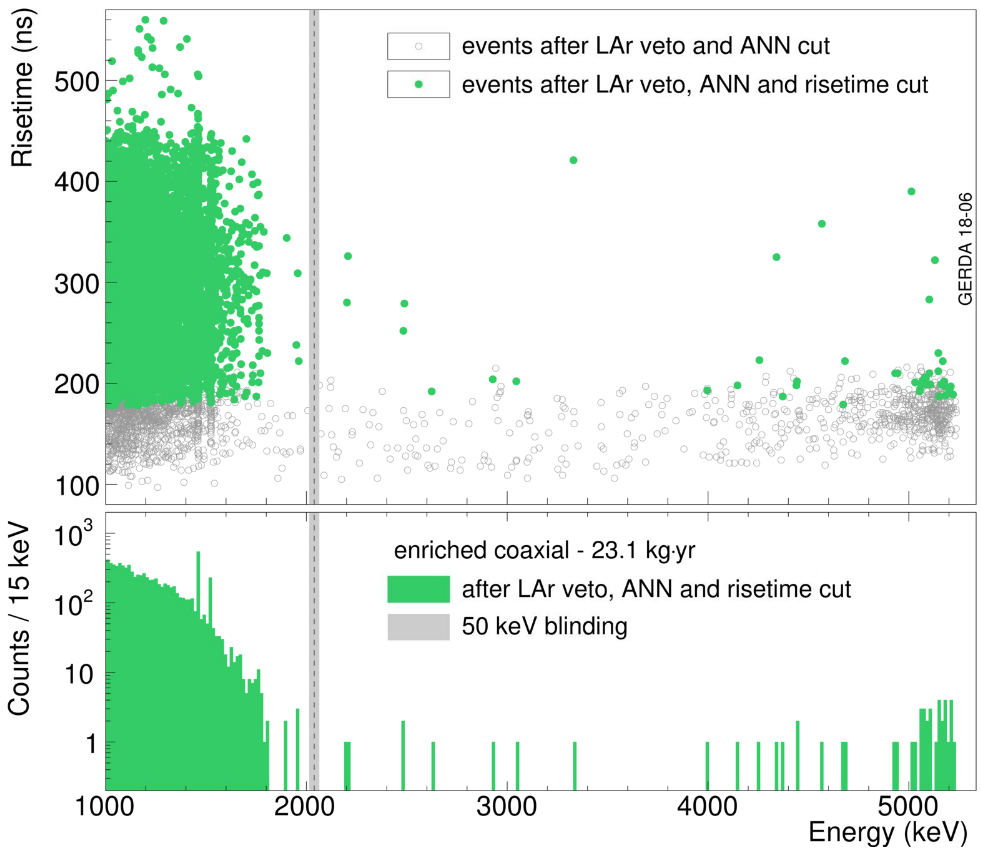
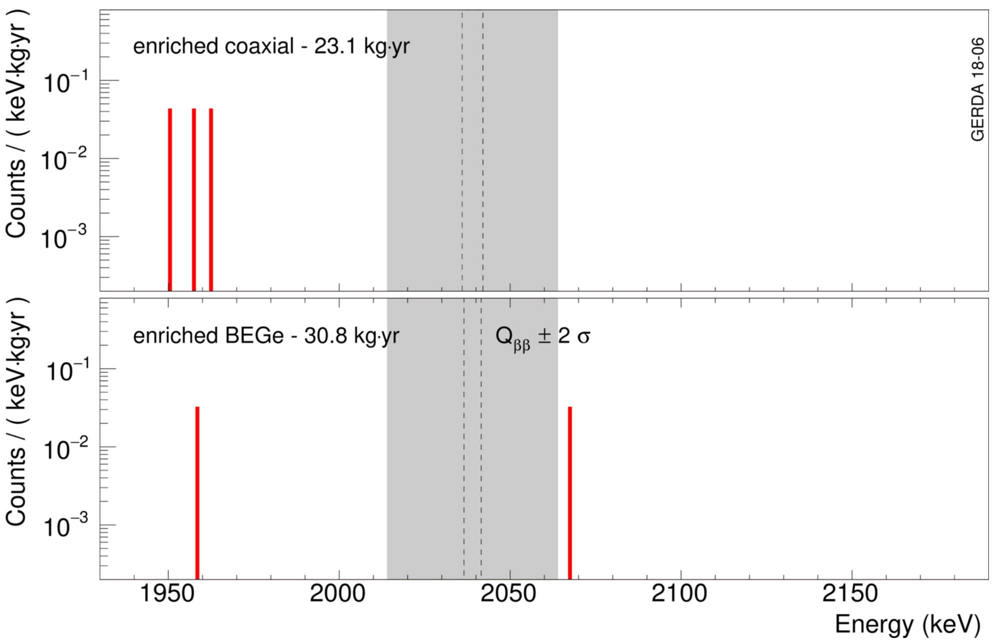
- acceptance from pulse shape simulations, cross-checked with $2\nu\beta\beta$ events

	$0\nu\beta\beta$ acceptance
coaxials	**(84±5)% x (85±1)%**

- additional α rejection based on (fast) signal **rise time**, tuned after ANN MSE rejection
- acceptance from $2\nu\beta\beta$ events



Background index

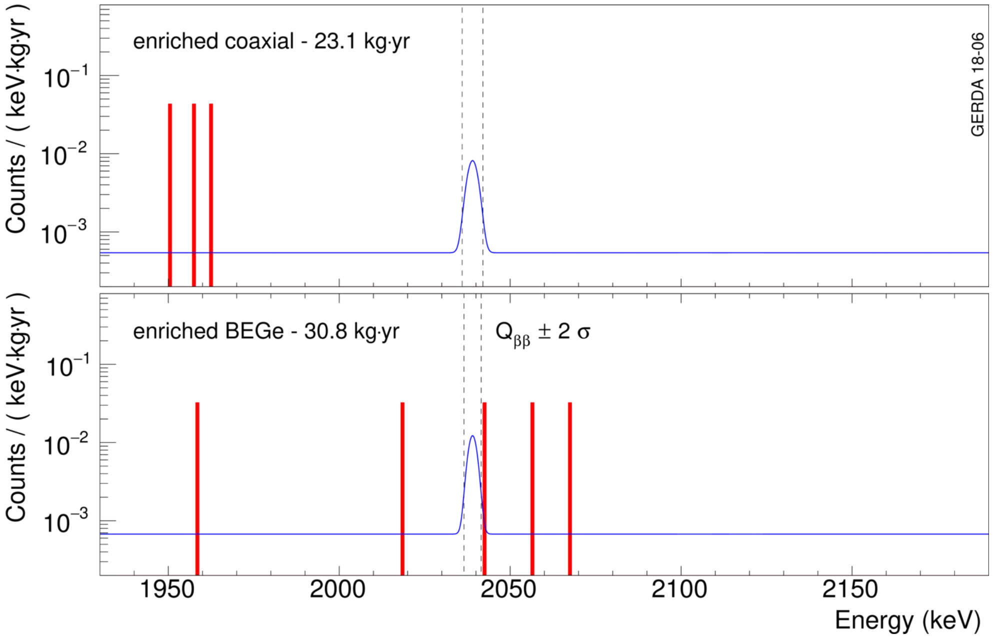


GERDA Phase II goals		
background	$\sim 10^{-3}$ cts/(keV·kg·yr)	✔
exposure	$\gtrsim 100$ kg·yr	
sensitivity	$T^{0\nu}_{1/2} \gtrsim 10^{26}$ yr	

- in [1930,2190] keV, excl. ±5 keV around ^{208}Tl (SEP), ^{214}Bi (FEP) and $Q_{\beta\beta}$

> **enriched coaxial:** $5.7^{+4.1}_{-2.6} \cdot 10^{-4}$ **cts/(keV·kg·yr)**
>
> **enriched BEGe:** $5.6^{+3.4}_{-2.4} \cdot 10^{-4}$ **cts/(keV·kg·yr)**

Statistical analysis



GERDA Phase II goals		
background	~10^{-3} cts/(keV·kg·yr)	✔
exposure	≳100 kg·yr	
sensitivity	$T^{0\nu}_{1/2} \gtrsim 10^{26}$ yr	✔

combined (+ Phase I) unbinned maximum likelihood fit (flat background + gaussian signal)
[Nature 544, 47 (2017)]

Frequentist:

- best fit $N^{0\nu} = 0$
- $\mathbf{T^{0\nu}_{1/2} > 0.9\cdot 10^{26}}$ **yr** (median sensitivity $\mathbf{T^{0\nu}_{1/2} > 1.1\cdot 10^{26}}$ **yr)** @ 90% C.L.

Bayesian (flat prior on $1/T^{0\nu}_{1/2}$):

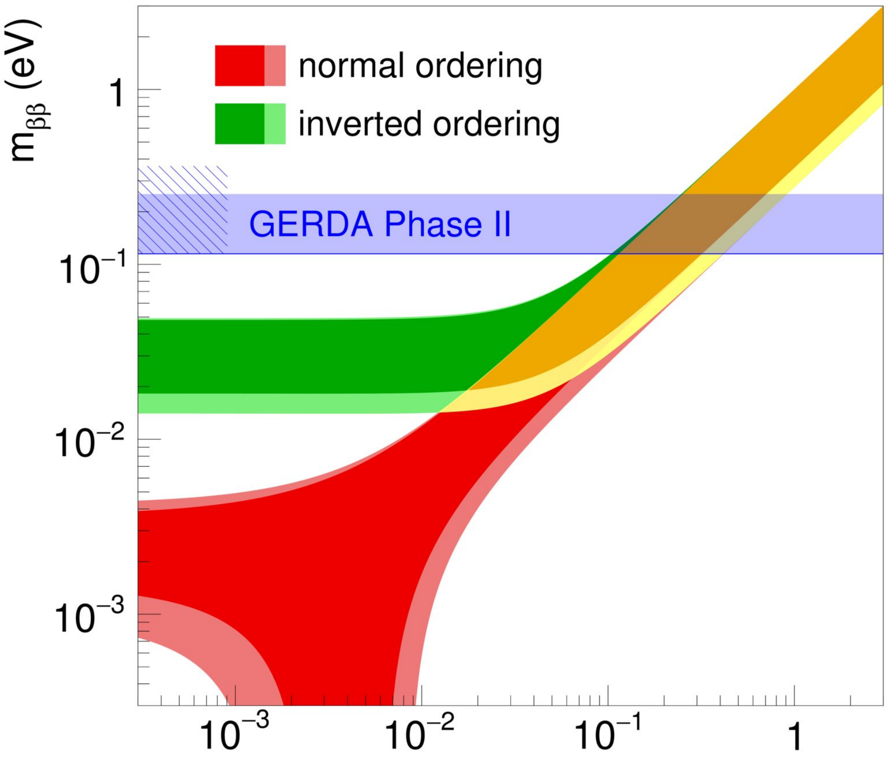
- $T^{0\nu}_{1/2} > 0.8\cdot 10^{26}$ yr (median sensitivity $T^{0\nu}_{1/2} > 0.8\cdot 10^{26}$ yr) @ 90% C.I.
- Bayes factor $P(H_{signal+bkg})/P(H_{bkg}) = 0.054$

Conclusions

"GERDA performs a high resolution background-free $0\nu\beta\beta$ decay search approaching $T^{0\nu}_{1/2}$ beyond 10^{26} yr"

- recent result:
  $T^{0\nu}_{1/2}$ > $0.9 \cdot 10^{26}$ yr @ 90% C.L.

> upper limit on
  $m_{\beta\beta}$ < (0.11–0.26) eV
  NME range from [Rept.Prog.Phys. 80 (2017) no.4, 046301]

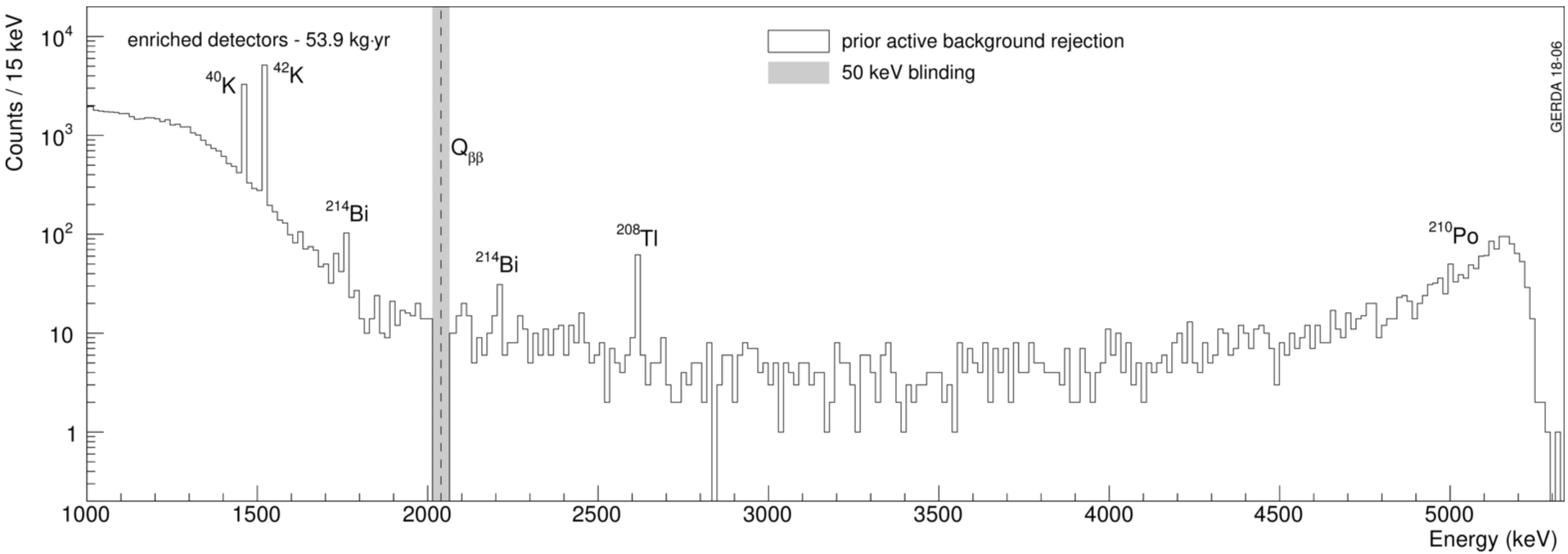


oscillation parameters from [NuFit v3.2 (ww.nu-fit.org)]

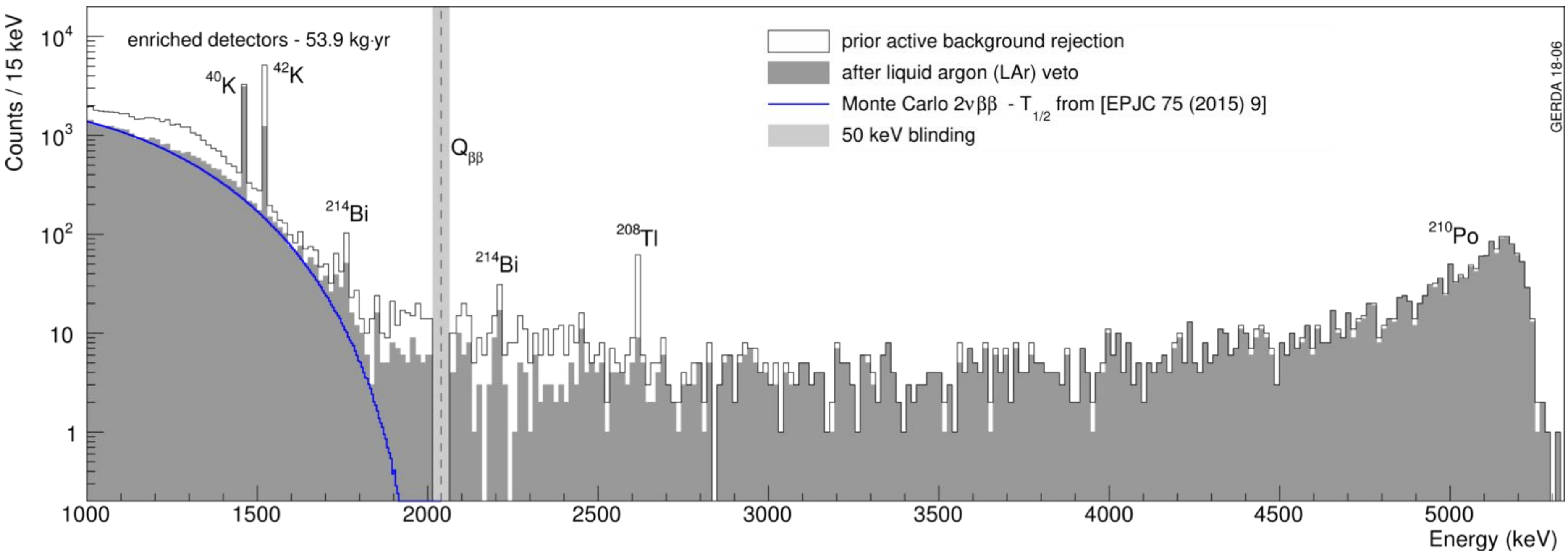
- GERDA keeps taking data
- **LEGEND-200** is in preparation to explore $T^{0\nu}_{1/2}$ beyond 10^{27} yr

〉BACKUP

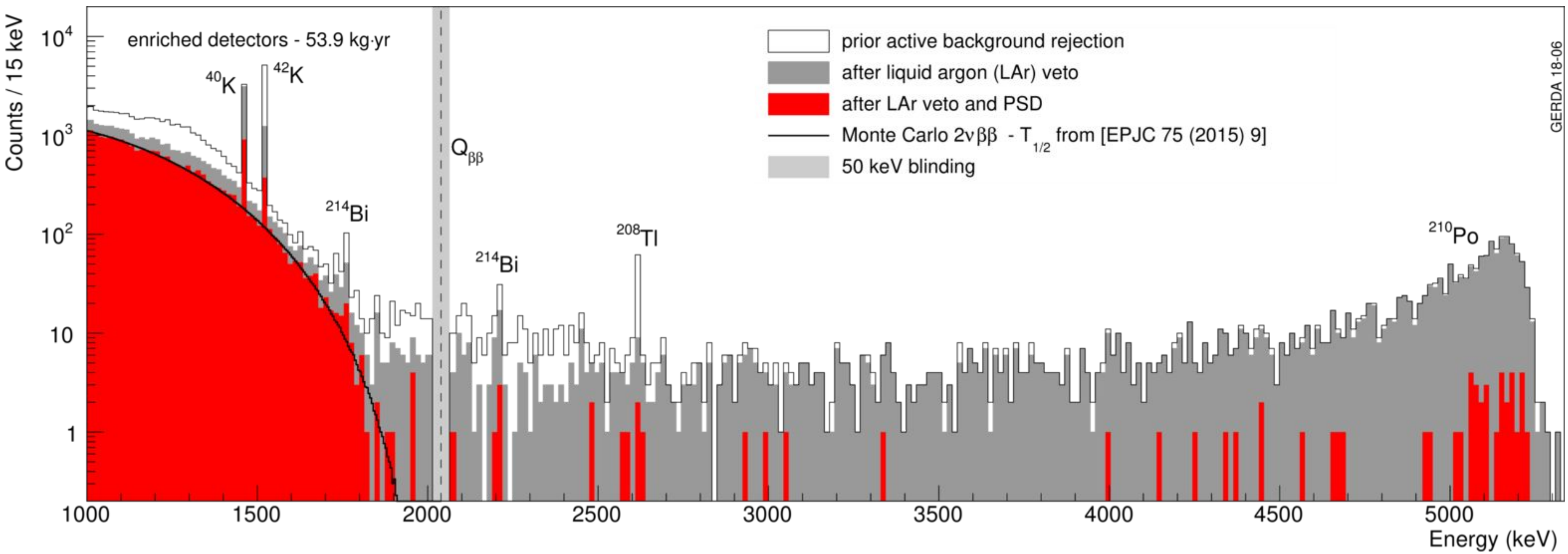
Physics spectrum



Physics spectrum



Physics spectrum



Statistical analysis

	exposure [kg*yr]	FWHM [keV]	total efficiency	background index [cts/(keV*kg*yr)]
Phase I golden	17.9	4.3(1)	0.57(3)	$(1.1\pm0.2)*10^{-2}$
Phase I silver	1.3	4.3(1)	0.57(3)	$(3.0\pm1.0)*10^{-2}$
Phase I BEGe	2.4	2.7(2)	0.66(2)	$(5.4^{+4.0}_{-2.5})*10^{-3}$
Phase I extra	1.9	4.2(2)	0.58(4)	$(4.6^{+4.3}_{-2.5})*10^{-3}$
Phase II EnrCoax	5.0	3.57(1)	0.52(4)	$(3.5^{+2.1}_{-1.5})*10^{-3}$
Phase II EnrCoax_2	23.1	3.57(1)	0.48(4)	$\mathbf{(5.7^{+4.1}_{-2.6})*10^{-4}}$
Phase II EnrBEGe	30.8	2.96(1)	0.60(2)	$\mathbf{(5.6^{+3.4}_{-2.4})*10^{-4}}$
total	**82.4**			

combined unbinned maximum likelihood fit (flat background + gaussian signal)

- **Frequentist:** test statistics and method à la [Nature 544, 47 (2017)]
- **Bayesian:** flat prior on $1/T^{0\nu}_{1/2}$ between 0 and 10^{-24} yr^{-1}
- systematic uncertainties folded as pull terms by Monte Carlo