XIX International Workshop
on Neutrino Telescopes

18-26 February 2021
Online

The GERDA experiment

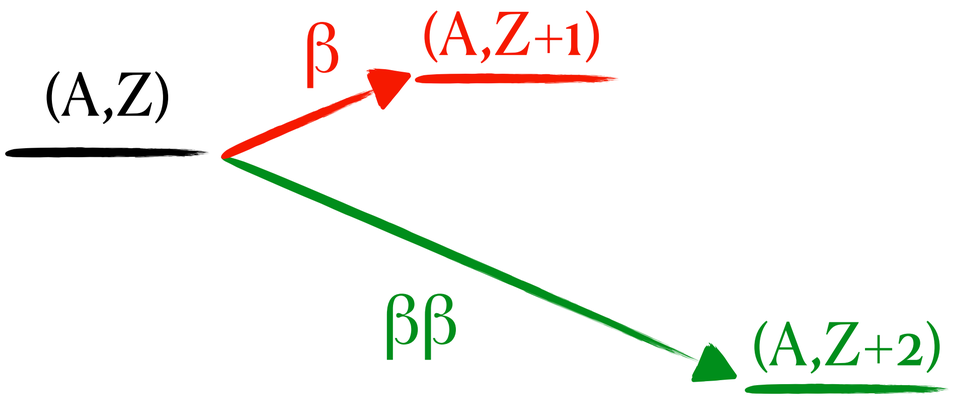
on the search for neutrinoless double-beta decay

T. Comellato (TUM) on behalf of the GERDA collaboration

Double-beta decay

What is double-beta decay

$$(A, Z) \rightarrow (A, Z+1) + e^- + \bar{\nu}_e$$



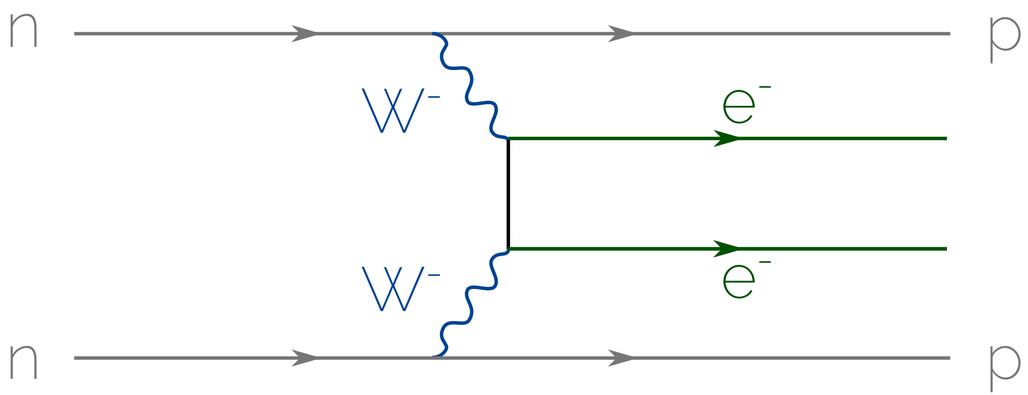
$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$$

- For a few nuclei, single β-decay is forbidden
- But: simultaneous β-decay of 2 neutrons is allowed
- Hypothesized in 1930's
  - $T_{1/2} > \mathcal{O}(10^{17})$ y [Goeppert-Mayer, M, *Phys Rev* 48 (1935), no. 6, 512–516]
- Measured in several isotopes (^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, ^{136}Xe...)
  - $T_{1/2} \approx \mathcal{O}(10^{18\div21})$ y

Double-beta decay

What is neutrinoless double-beta decay

$$2n \rightarrow 2p + 2e^-$$

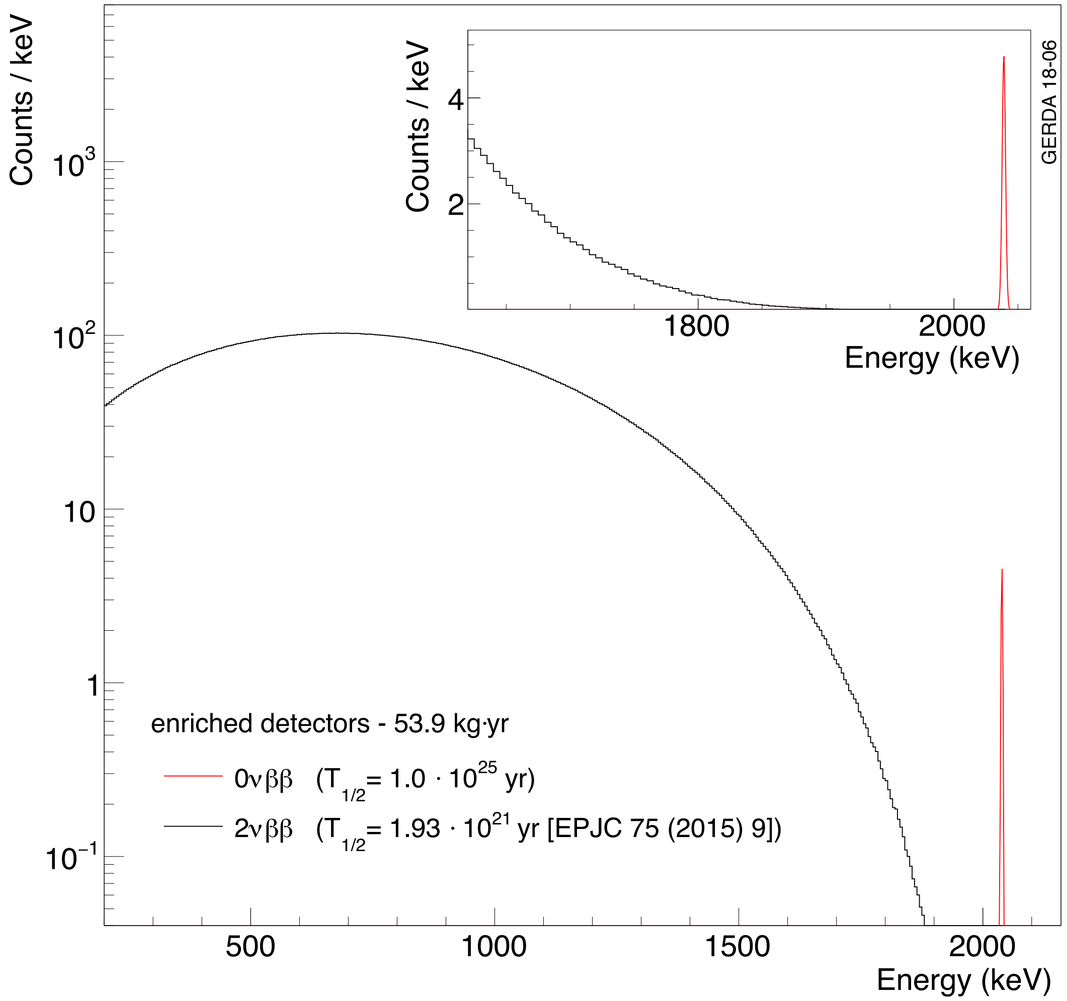


$$(A, Z) \rightarrow (A, Z+2) + 2e^- + \cancel{2\nu_e}$$

- Double-beta decay channel without emission of neutrinos
- Creation of matter without anti-matter
  - Lepton number not conserved $\Delta L = 2$
  - Not allowed in the Standard Model
- Portal to new physics

Detecting double-beta decay

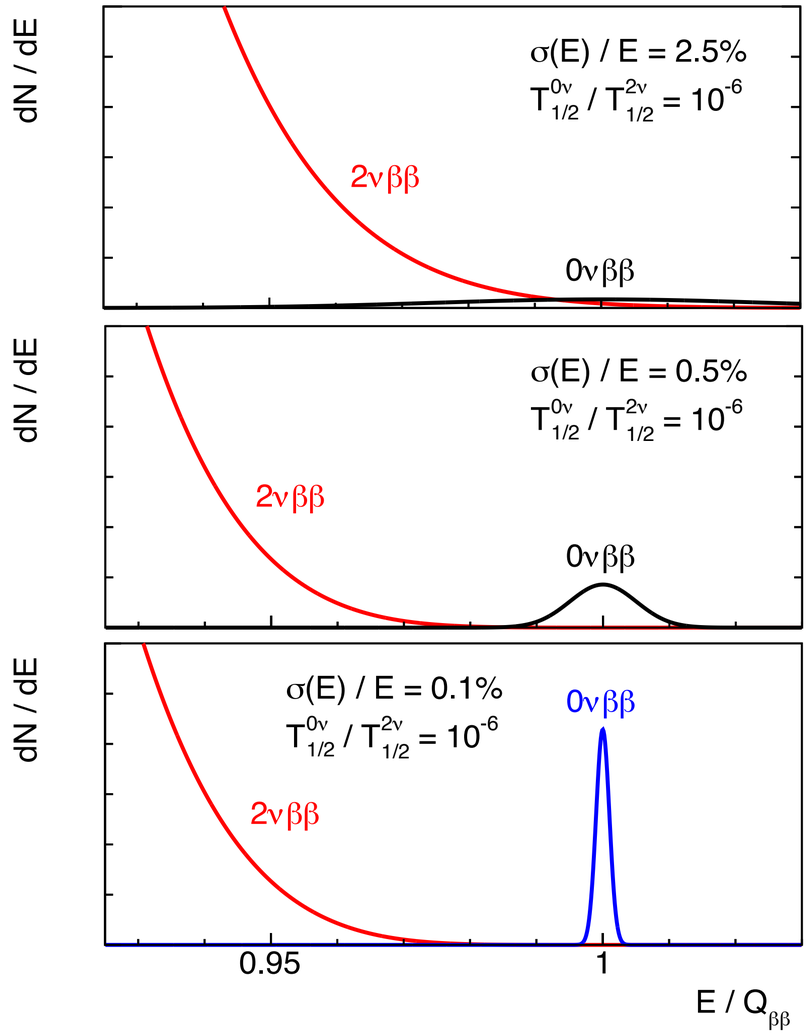
The experimental signature



- Signature:
  - $0\nu\beta\beta$: energy deposition of 2 electrons @ $Q_{\beta\beta}$ (= 2039 keV for ^{76}Ge)
  - $2\nu\beta\beta$: energy deposition of 2 electrons @ $E < Q_{\beta\beta}$
- Experimental challenge:
  - No background @$Q_{\beta\beta}$ for $\mathcal{O}(10)$ y

Detecting double-beta decay

...with the GERmanium Detector Array experiment

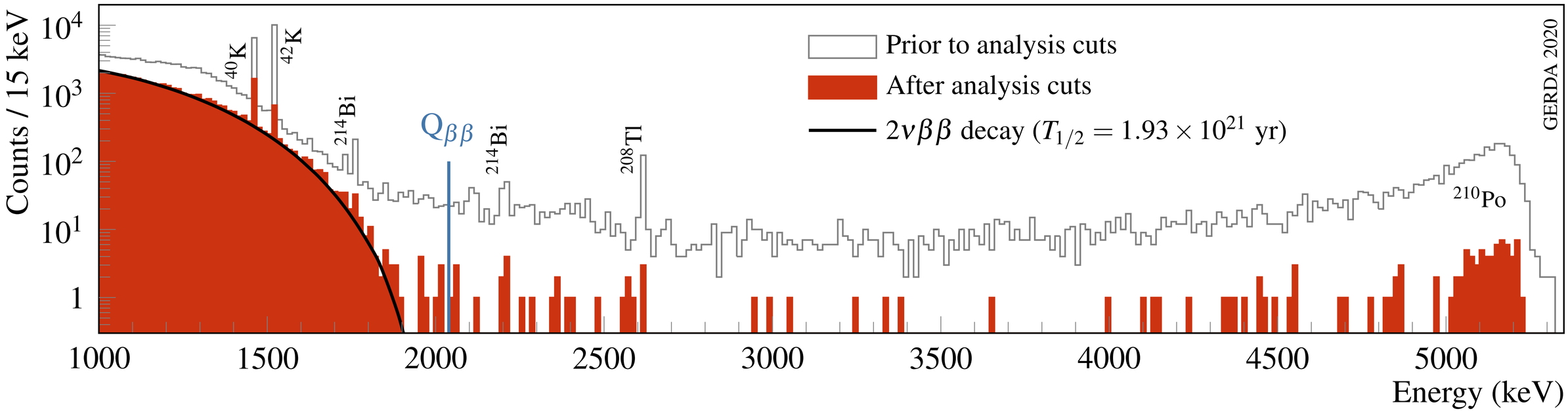


- Germanium promising candidate since 1967
  [E. Fiorini et al., *Phys Lett B*, 25 (1967), no. 10, 602–603]
- Use HPGe detectors enriched in ^{76}Ge
  - Source = detector
  - Density
  - Radio-purity [GERDA, Astropart.Phys. 91 (2017) 15-21]

  → High detection efficiency
  - Excellent energy resolution ($\mathcal{O}(0.1\%)$)
  - Event topology Discrimination - Pulse Shape Discrimination (PSD)

Detecting double-beta decay

...with the GERmanium Detector Array experiment



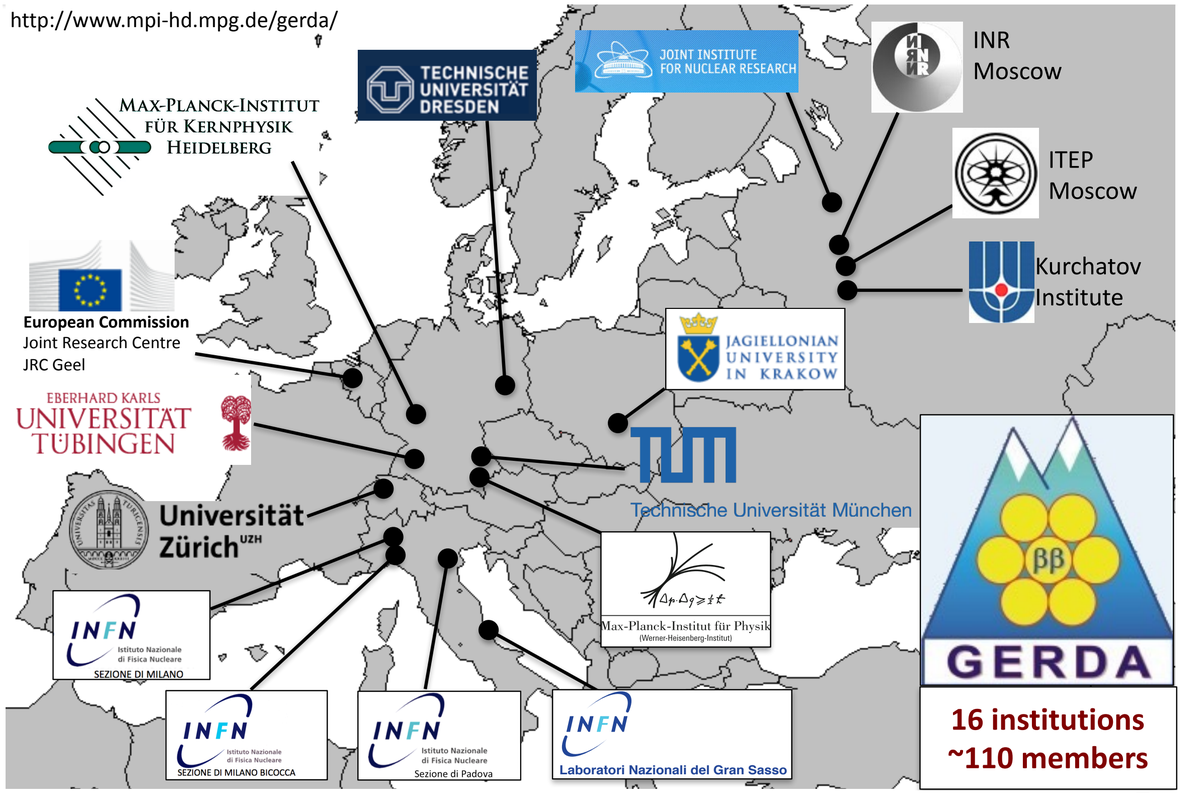
[GERDA, *Phys Rev Lett* **125** (2020), 252502]

- Background expectations @($Q_{\beta\beta} \pm 2\sigma$) = 0.3 counts **after 103.7 kg yr exposure**

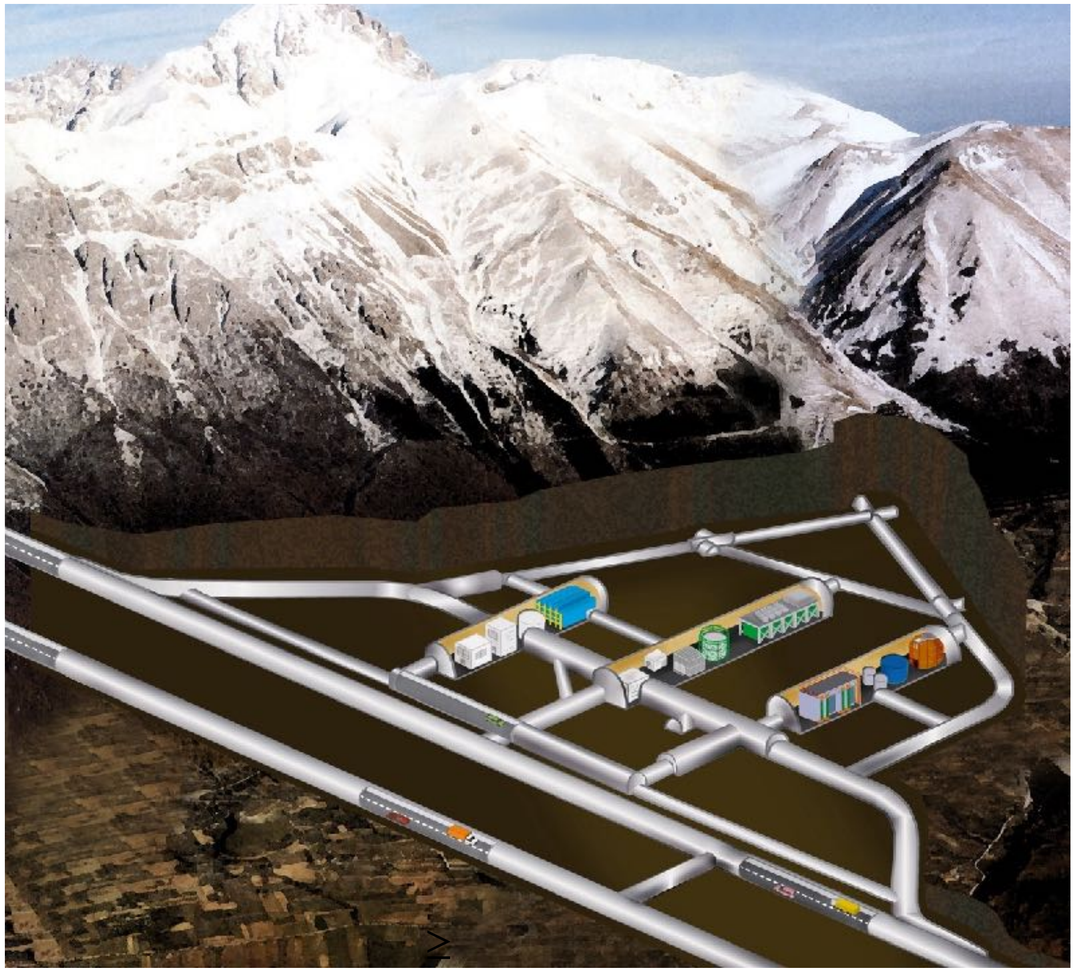
High resolution, background-free search of $0\nu\beta\beta$ decay

The GERDA collaboration

- Collaboration meeting in Zurich (2019)



The GERDA experiment



- Located @ Laboratori Nazionali del Gran Sasso (Italy)
- Shielded by 3500 m.w.e.

	Goals
Background	10^{-3} cts/(keV kg yr)
Exposure	> 100 kg yr
Sensitivity	$T_{1/2}^{0\nu\beta\beta} \geq 10^{26}$ yr

The GERDA experiment

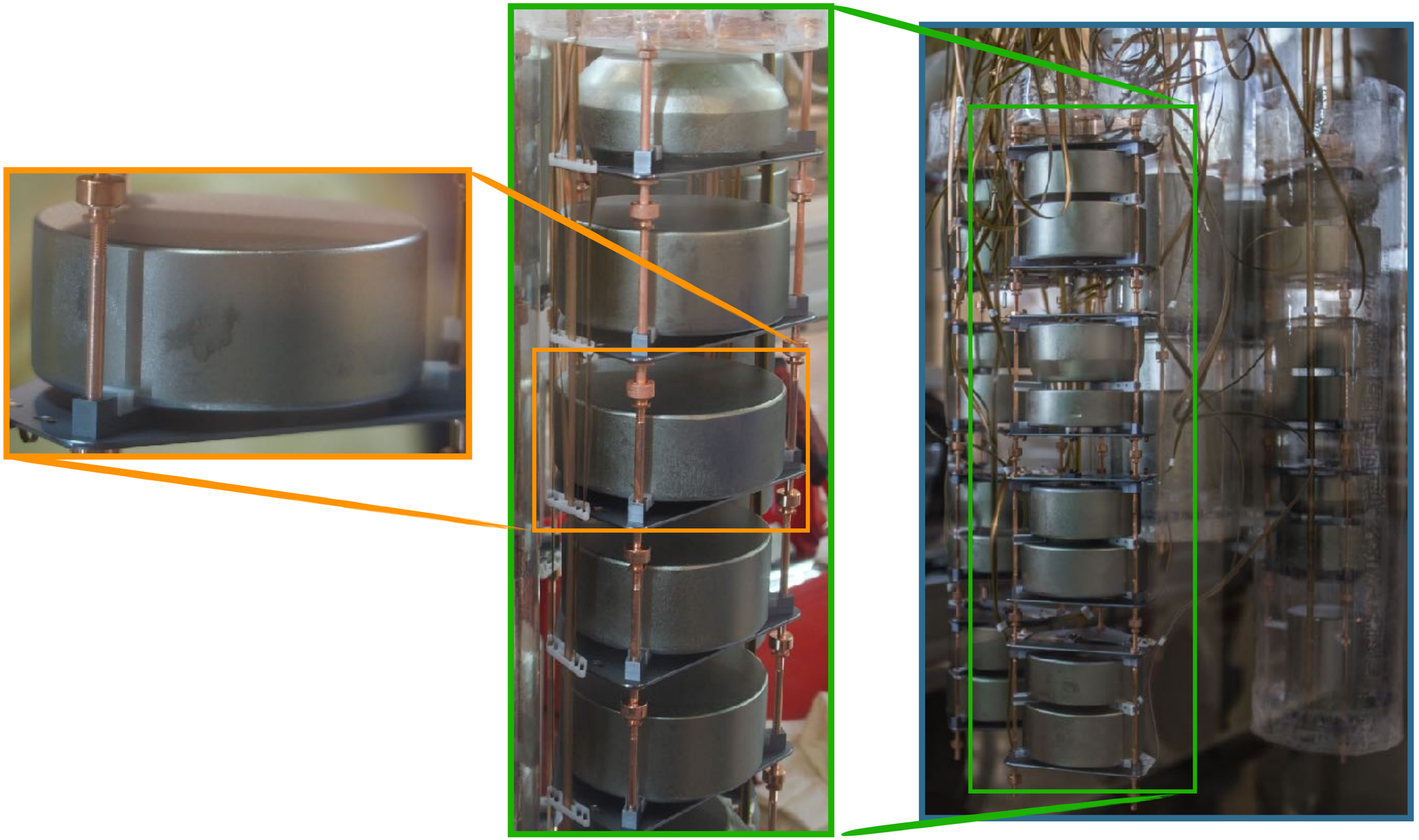
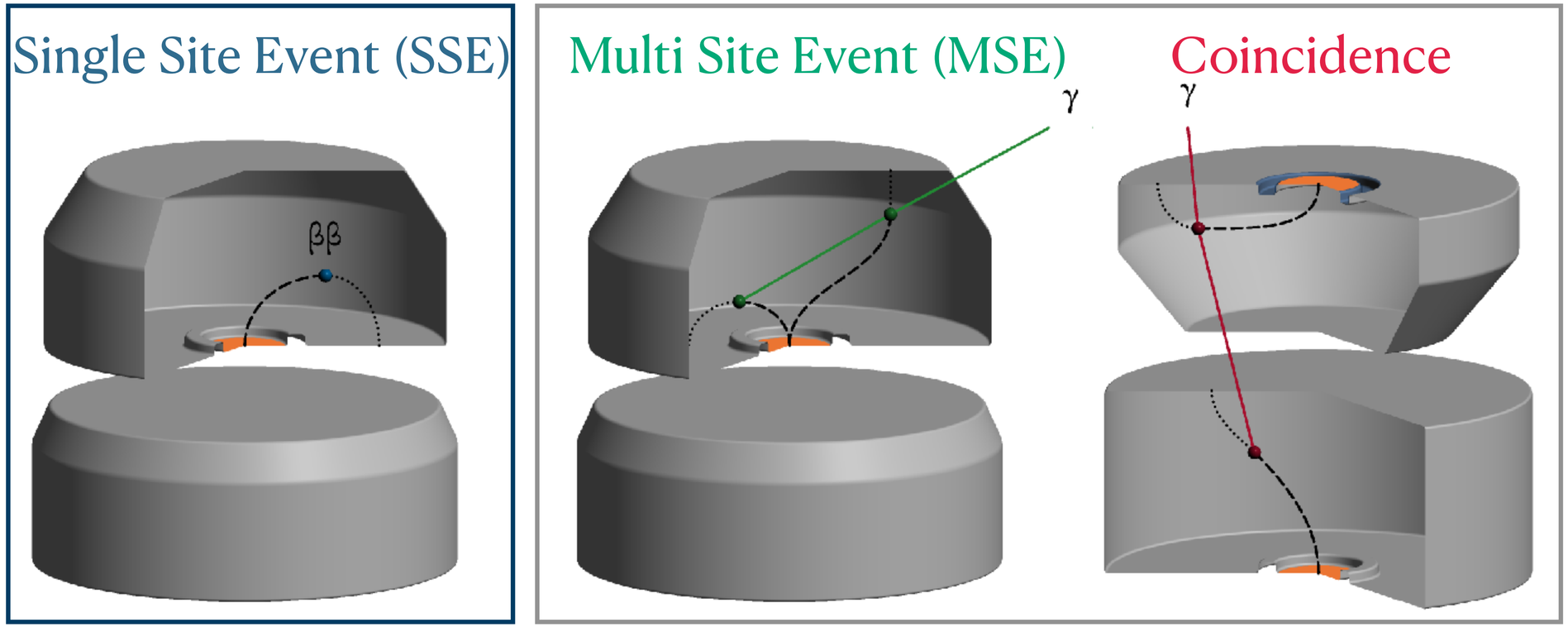


Image produced with: https://github.com/gipert/gedet-plots

Event discrimination in germanium

Signal and background



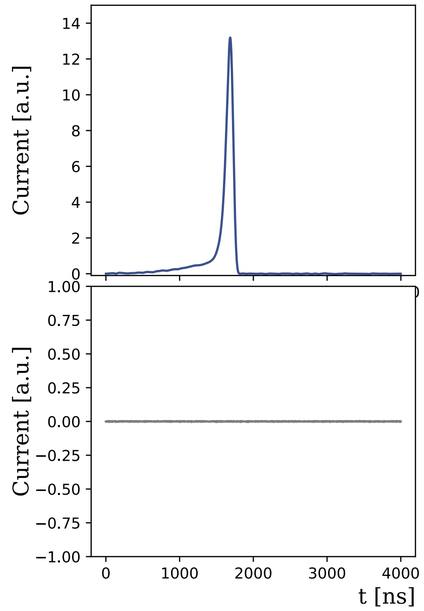
Signal

Background

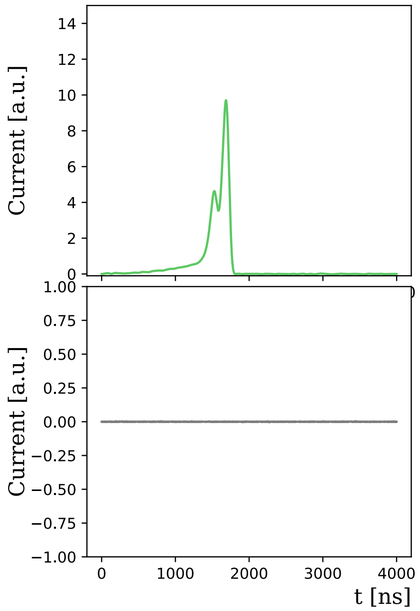
Event discrimination in germanium

Signal and background

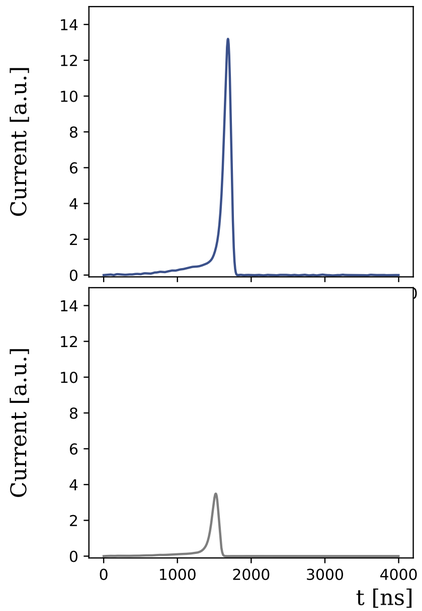
Single Site Event (SSE)



Multi Site Event (MSE)



Coincidence

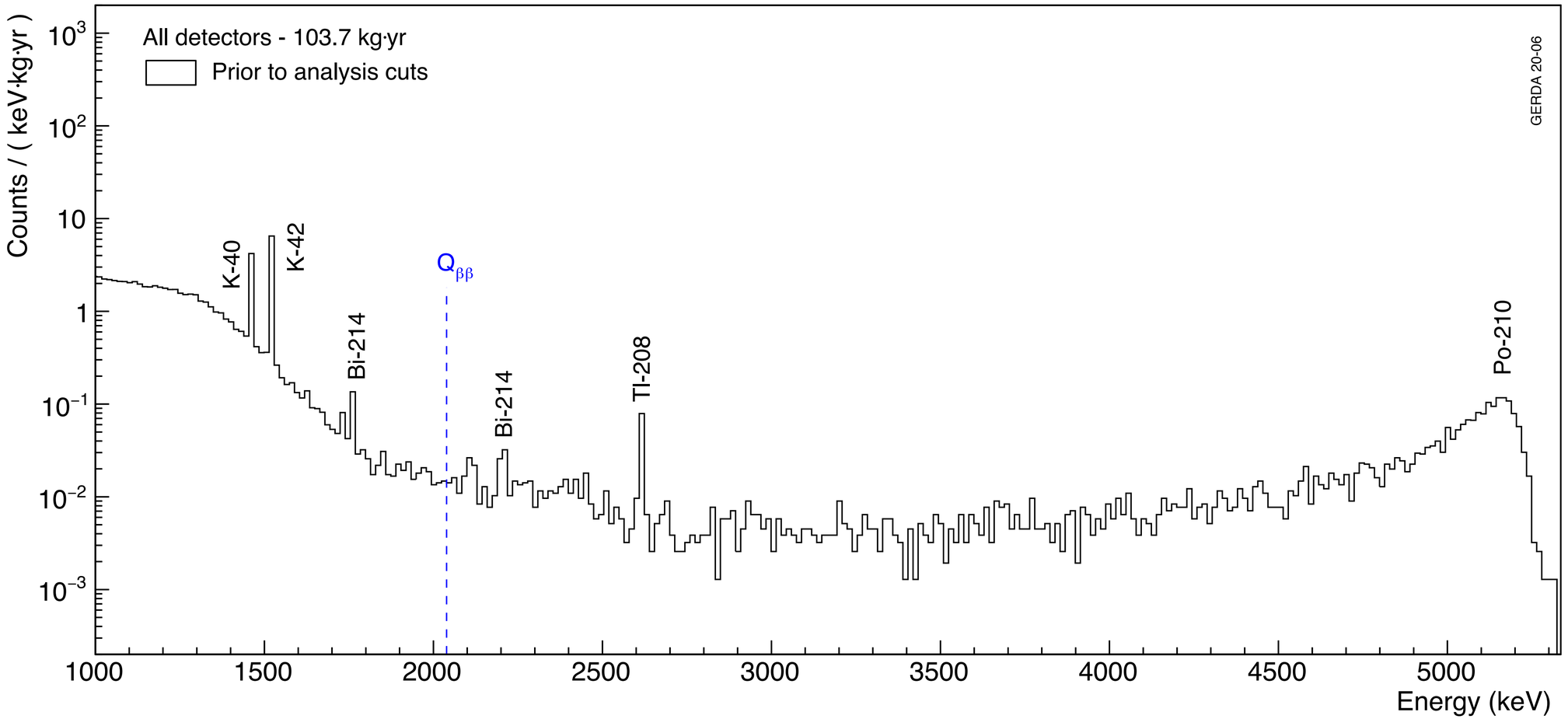


Signal

Background

Active background suppression

Performance



Active background suppression

Performance

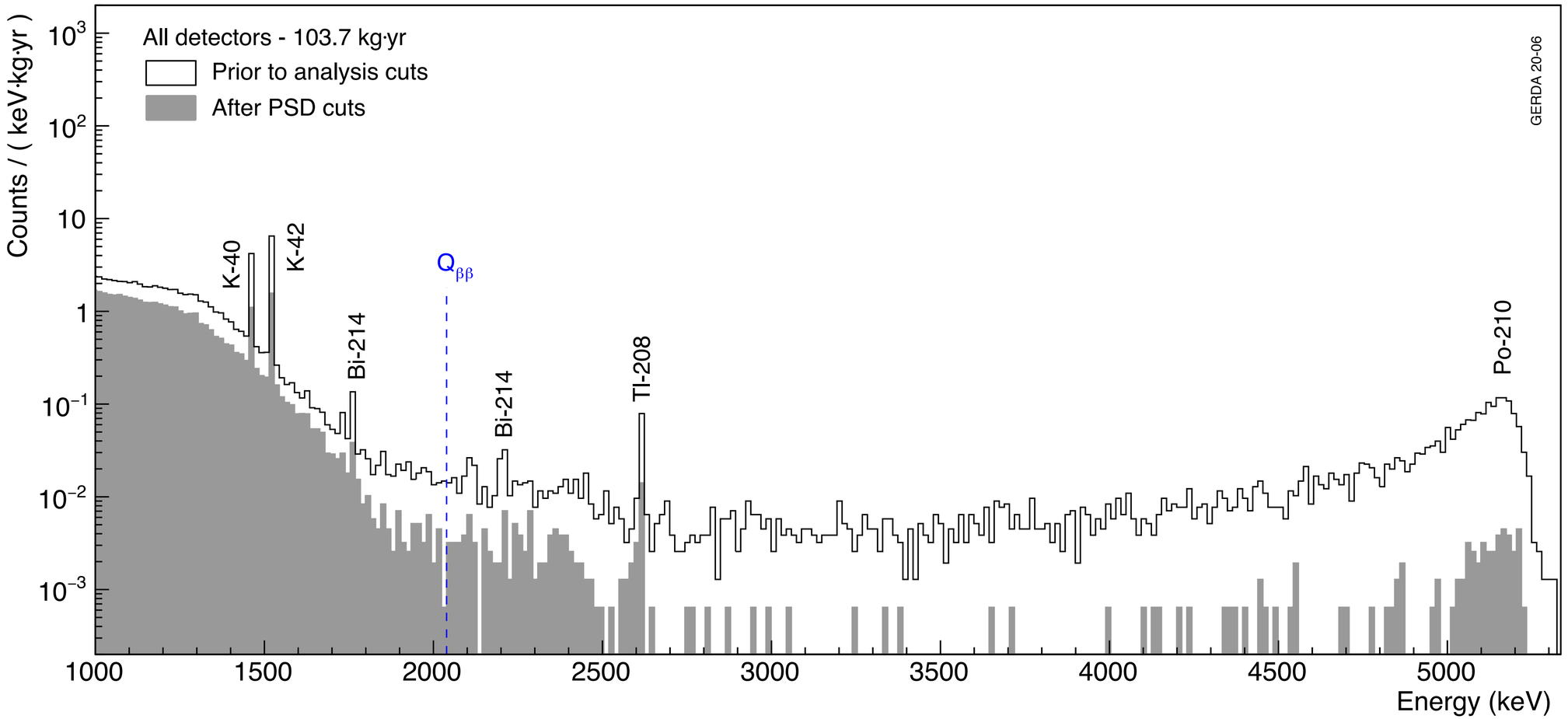
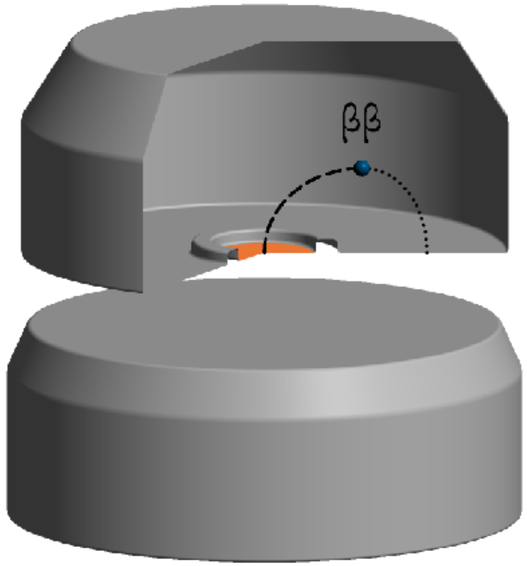


Image produced with: https://github.com/gipert/gedet-plots

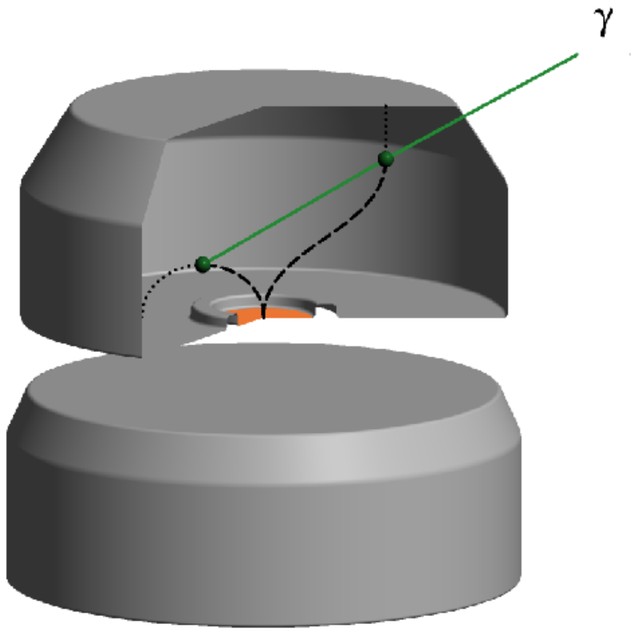
Pulse Shape Discrimination

Signal and background

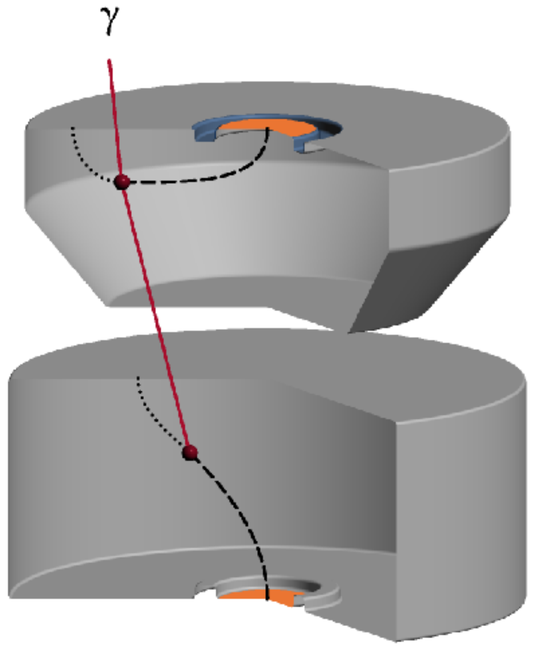
Single Site Event (SSE)



Multi Site Event (MSE)



Coincidence



Signal

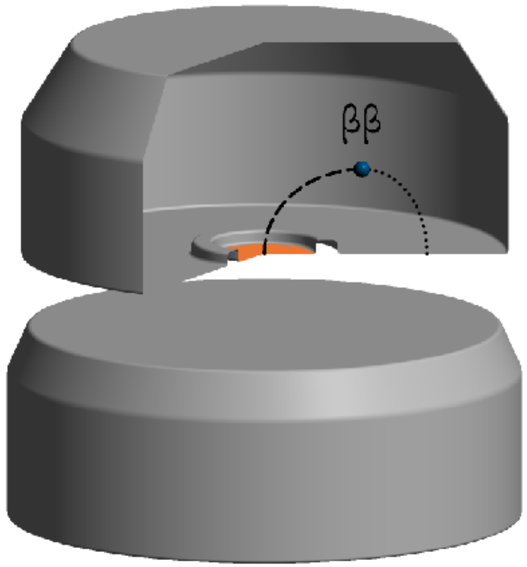
Background

Image produced with: https://github.com/gipert/gedet-plots

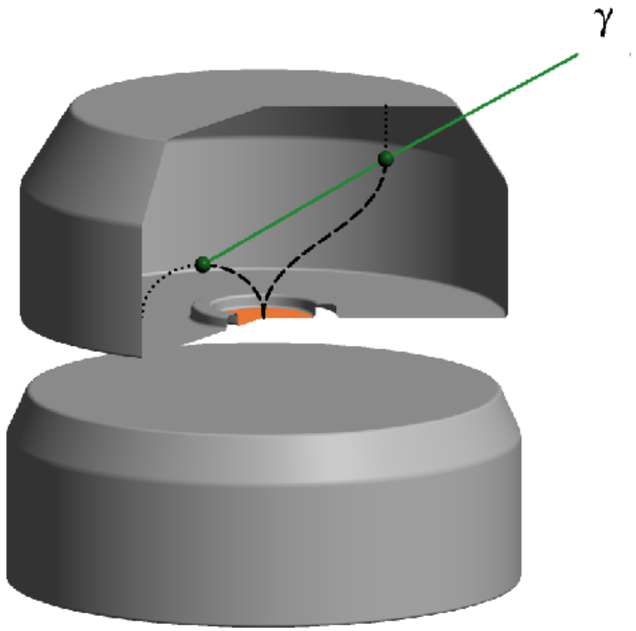
Pulse Shape Discrimination

Signal and background

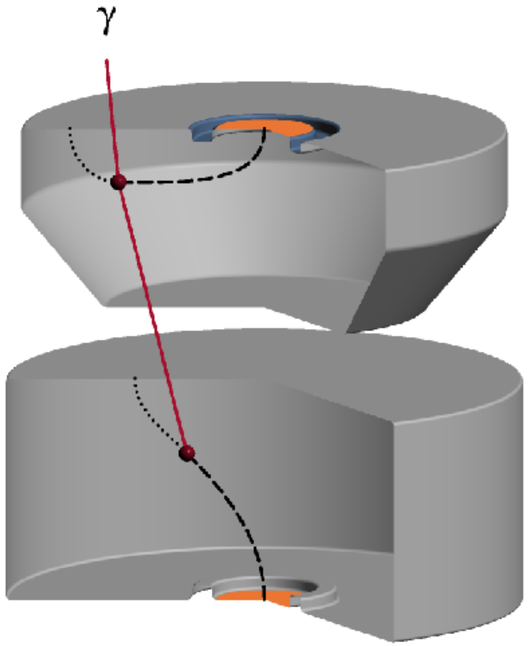
Single Site Event (SSE)



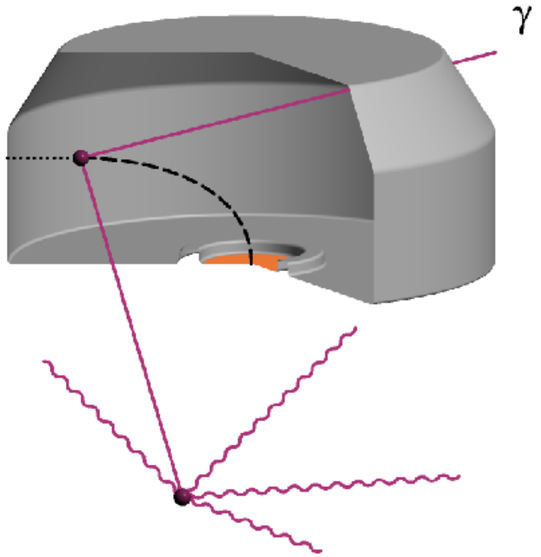
Multi Site Event (MSE)



Coincidence



Partial energy deposition



Signal

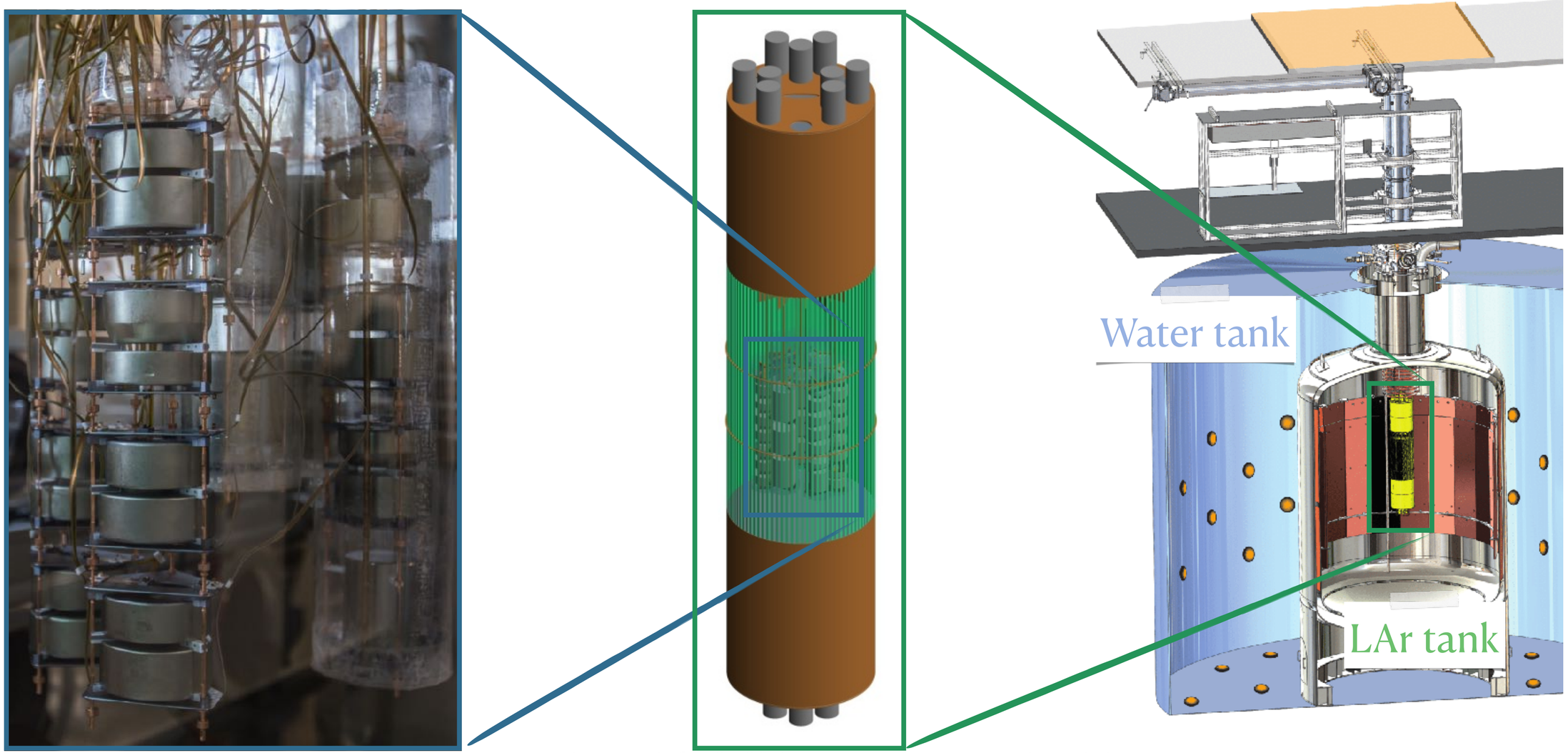
Background

Surrounding liquid argon (LAr) tags these events

The LAr veto system

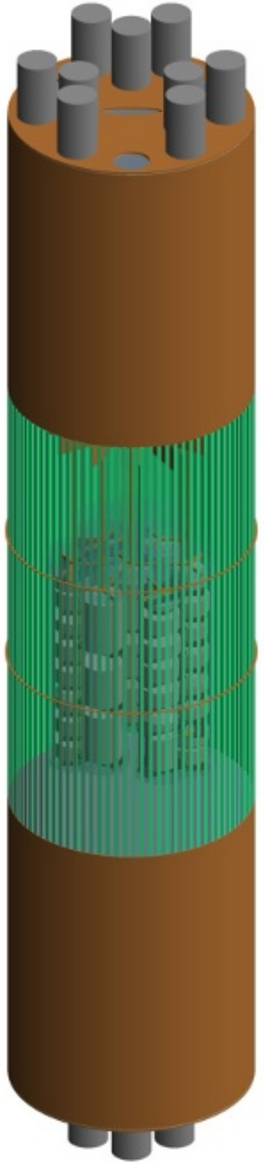
[GERDA, *European Phys J C* **78** (2018), 388]

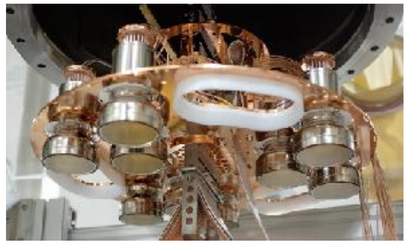
...and full GERDA

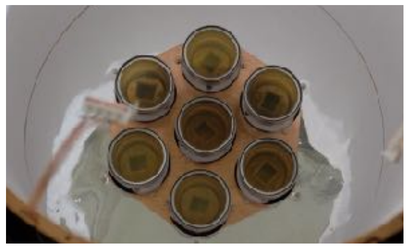


The LAr veto system

[GERDA, *European Phys J C* **78** (2018), 388]



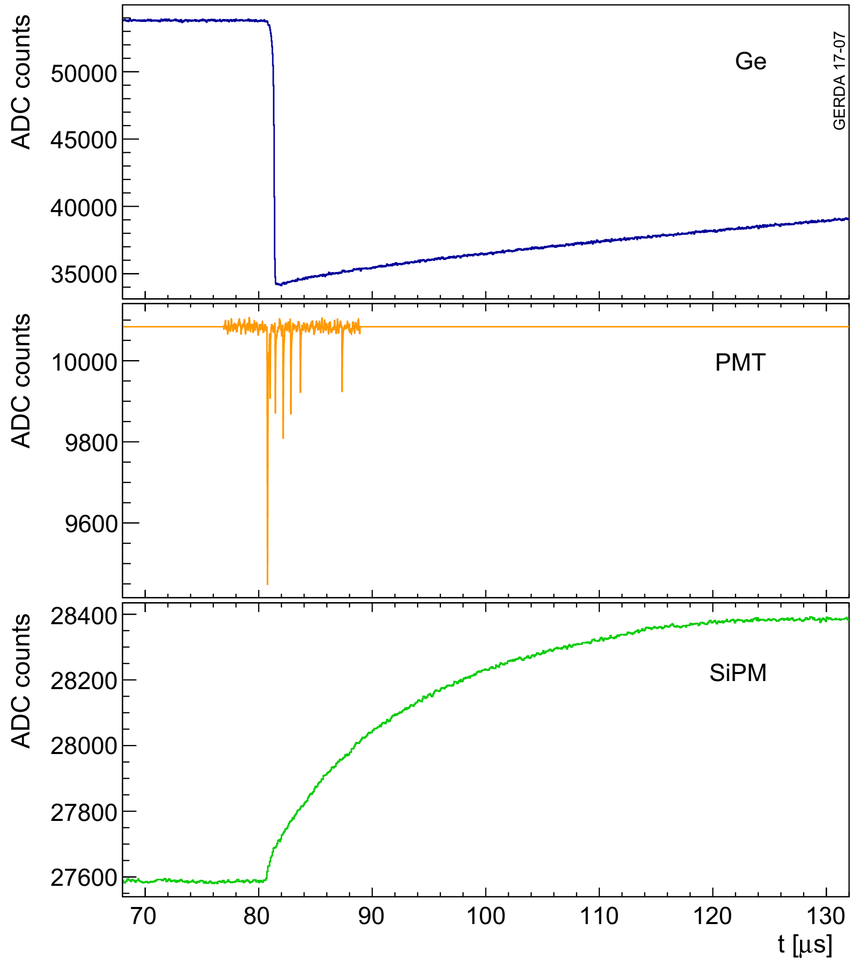




How it works

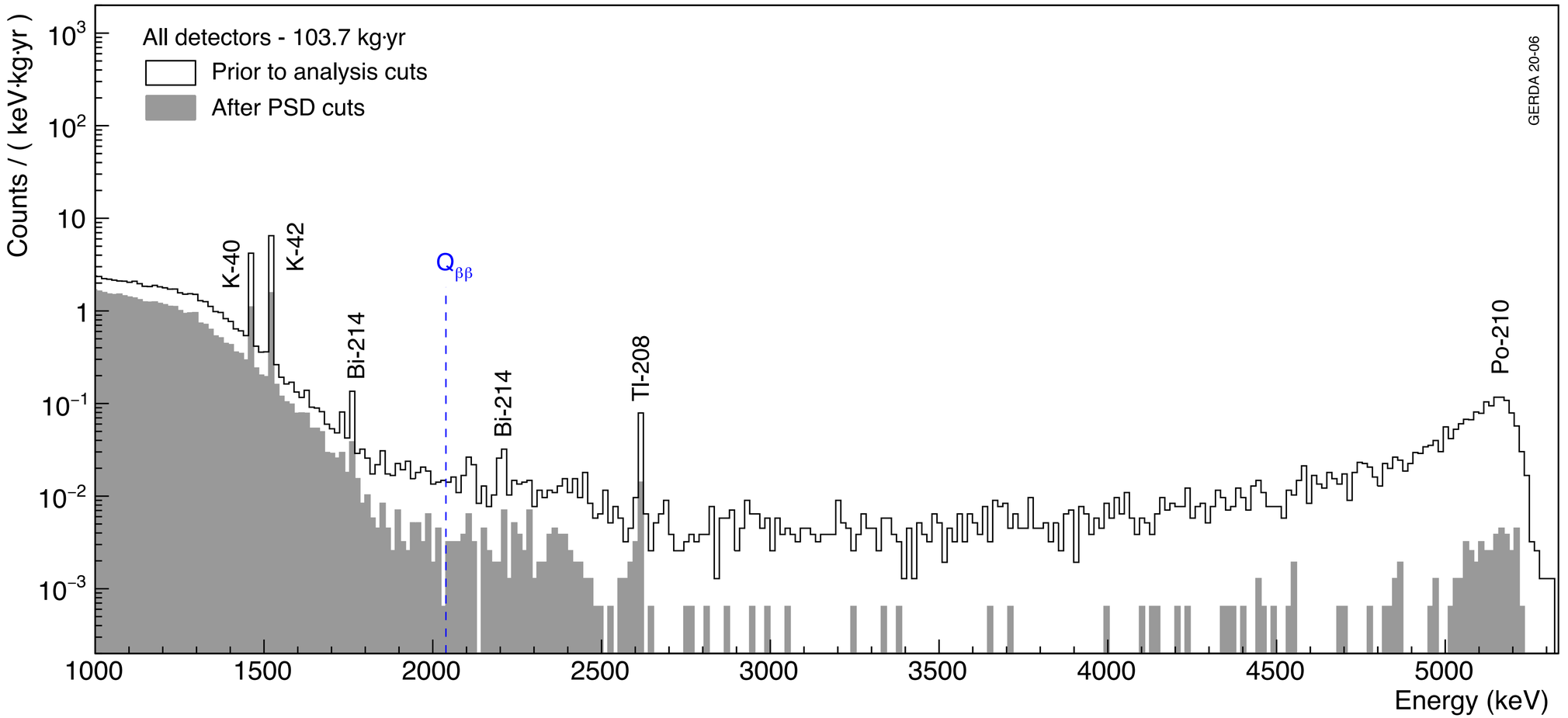
- 16 PMTs
- ~ 1.5 km light guiding fibers + SiPM readout
- Vetoes events in coincidence with Germanium
- Acceptance ($0\nu\beta\beta$) : ~98 %

[GERDA, *Phys Rev Lett* **125** (2020), 252502]



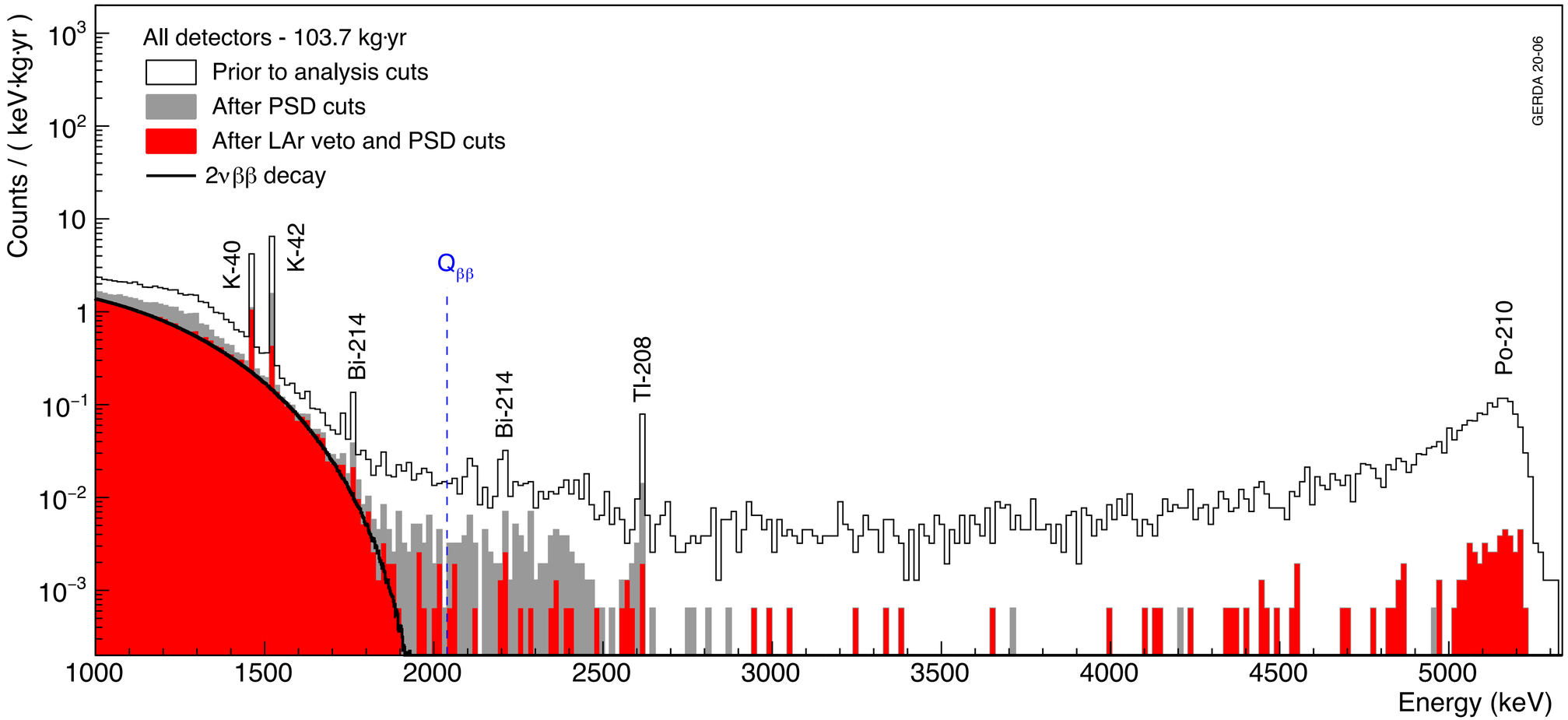
Active background suppression

Performance



Total active background suppression

Performance

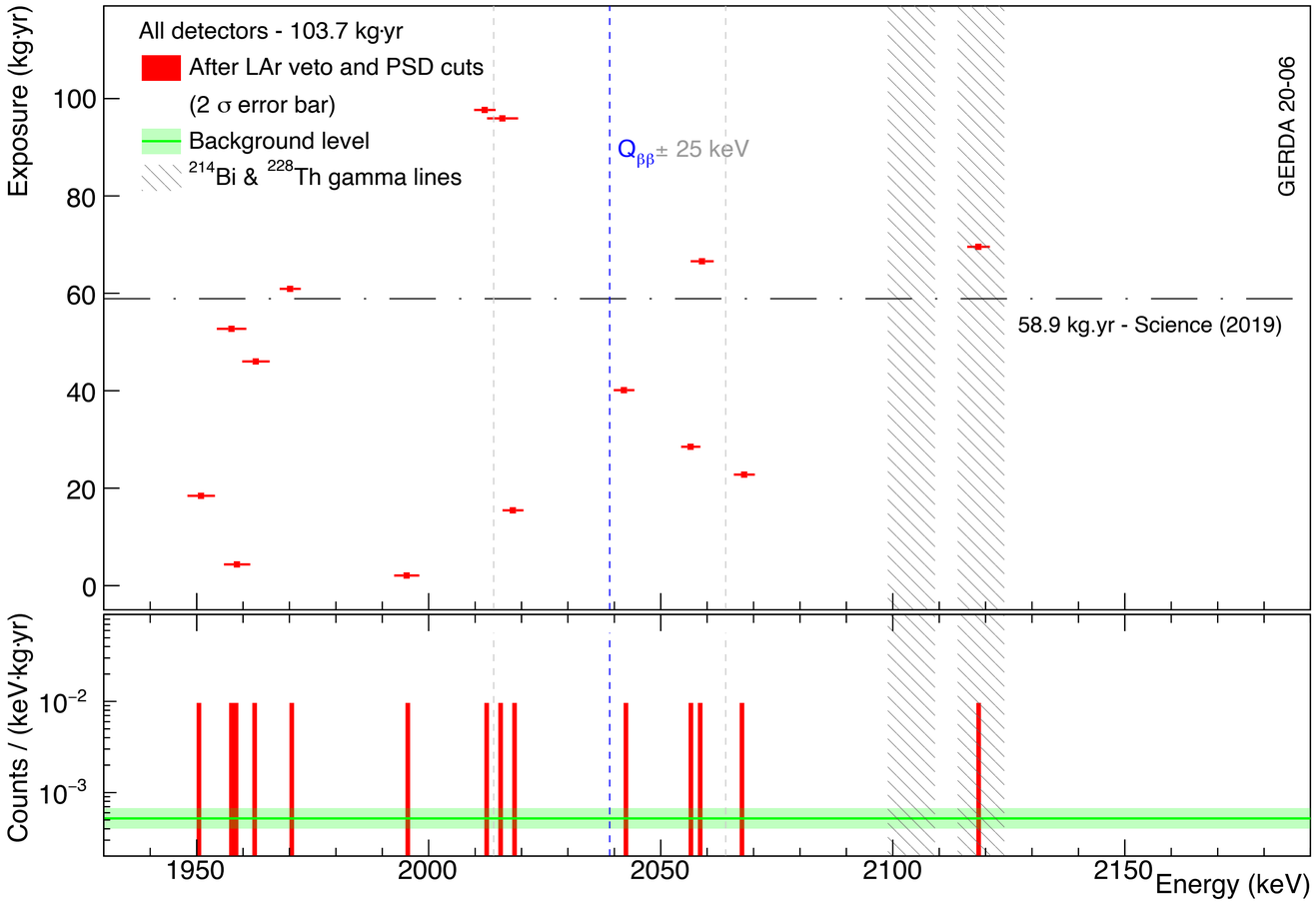


Final results @$Q_{\beta\beta}$

[GERDA, *Phys Rev Lett* **125** (2020), 252502]

Final Results of GERDA

...in the analysis window

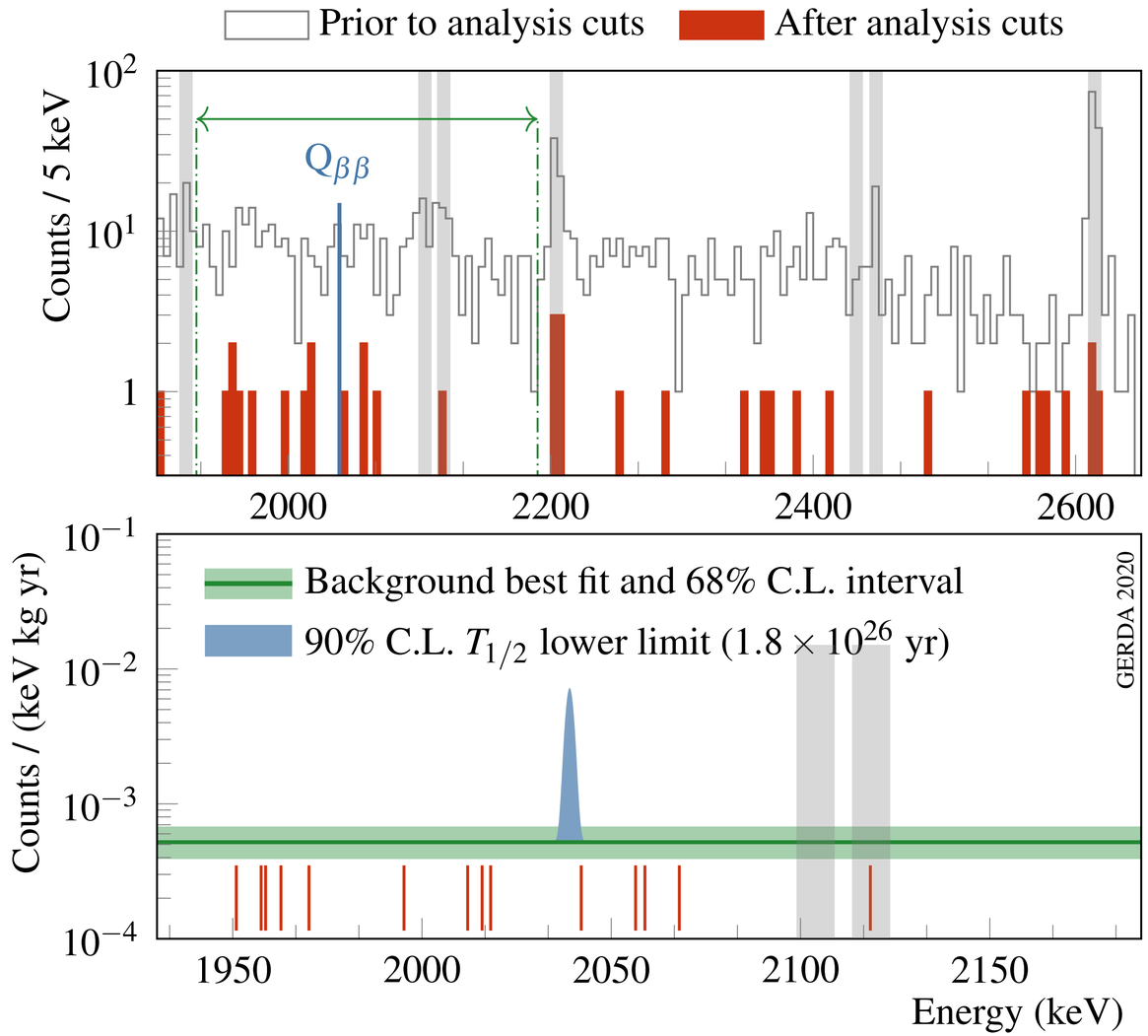


- Blind analysis around $Q_{\beta\beta}$
- Latest unblinding in May 2020
- 2 new counts in $Q_{\beta\beta} \pm 25$ keV
- No new counts @$Q_{\beta\beta}$
- Background:
  - $5.2^{+1.6}_{-1.3} \cdot 10^{-4}$ cts/(keV kg yr)

[GERDA, *Phys Rev Lett* **125** (2020), 252502]

Final Results of GERDA

...limits on $0\nu\beta\beta$



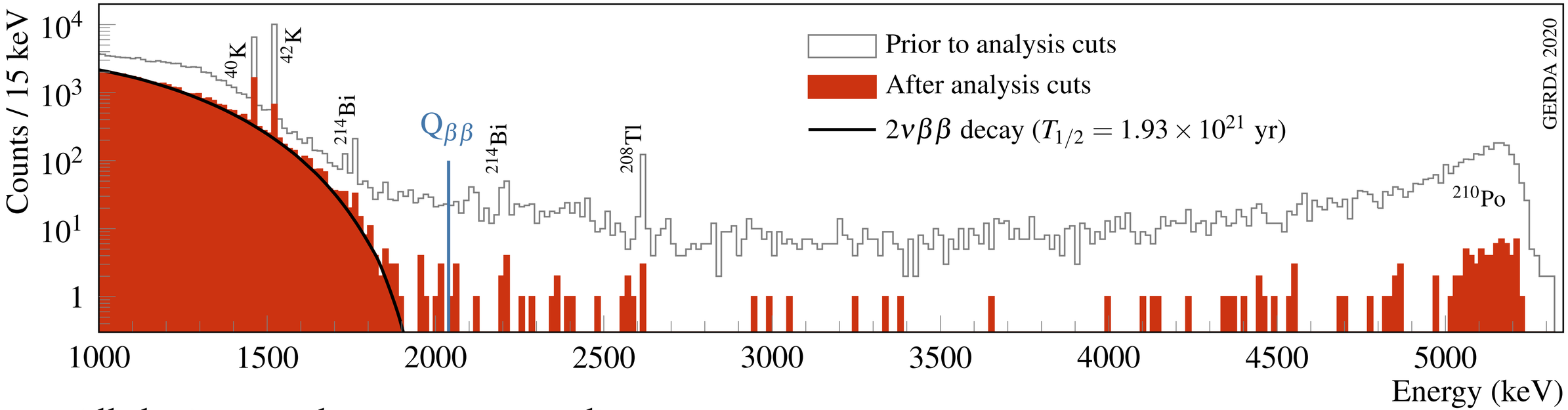
- Combined (data partitions, Phase I) unbinned maximum likelihood fit
  [GERDA, *Nature* **544** (2017), 47–52]
- Best fit for null signal strength
- Limit (and sensitivity) on $0\nu\beta\beta$ half-life:

$$T_{1/2}^{0\nu\beta\beta} > 1.8 \cdot 10^{26} \text{ yr (90\% C.L.)}$$

- Limits on $m_{\beta\beta}$:

$$m_{\beta\beta} < [79 - 180] \text{ meV}$$

Final Results of GERDA

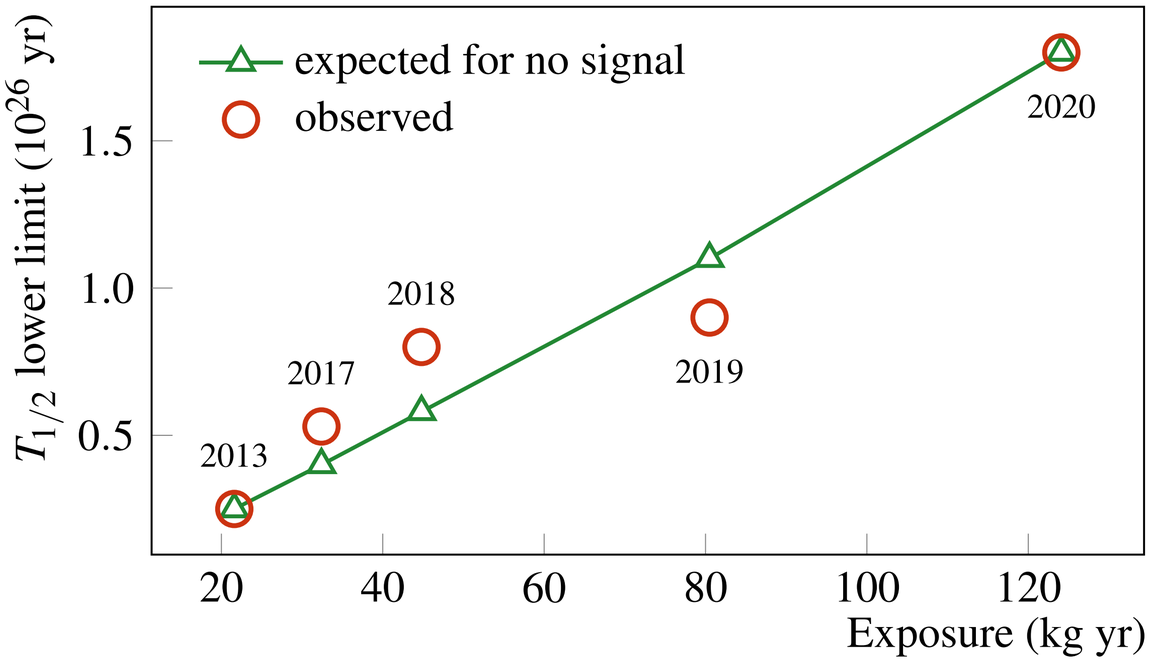


- All design goals are surpassed!

	Goals	Achievements
Background	10^{-3} cts/(keV kg yr)	$5.2^{+1.6}_{-1.3} \cdot 10^{-4}$ cts/(keV kg yr)
Exposure	$\geq$ 100 kg yr	103.7 kg yr (footnote Phase I)
Sensitivity	$T^{0\nu\beta\beta}_{1/2} \geq 10^{26}$ yr	$T^{0\nu\beta\beta}_{1/2} > 1.8 \cdot 10^{26}$ yr

Conclusions

- GERDA ran in background-free regime for the entire duration of its data taking
- Provides the most stringent constraints on the half-life of $0\nu\beta\beta$ decay



- Bright future ahead

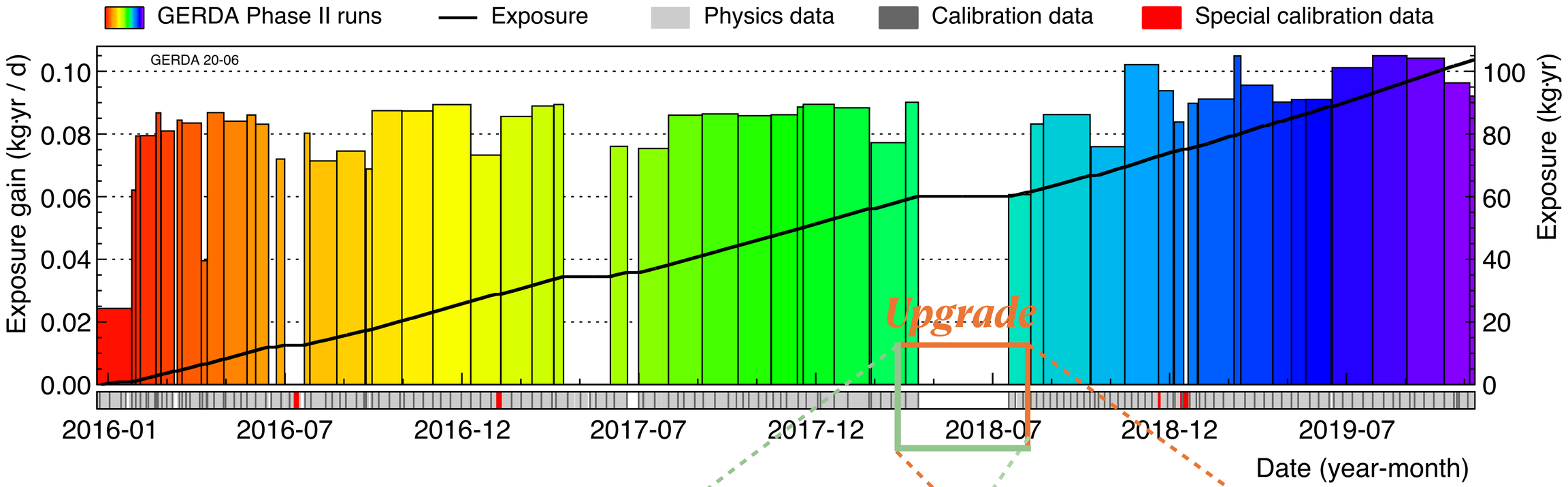
LEGEND

  - —>See R. Henning's talk #104

- Provides results on the search for exotic fermions —> see E. Bossio's poster #80

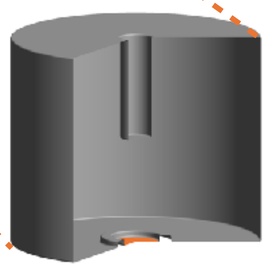
backup

The data taking of GERDA phase II



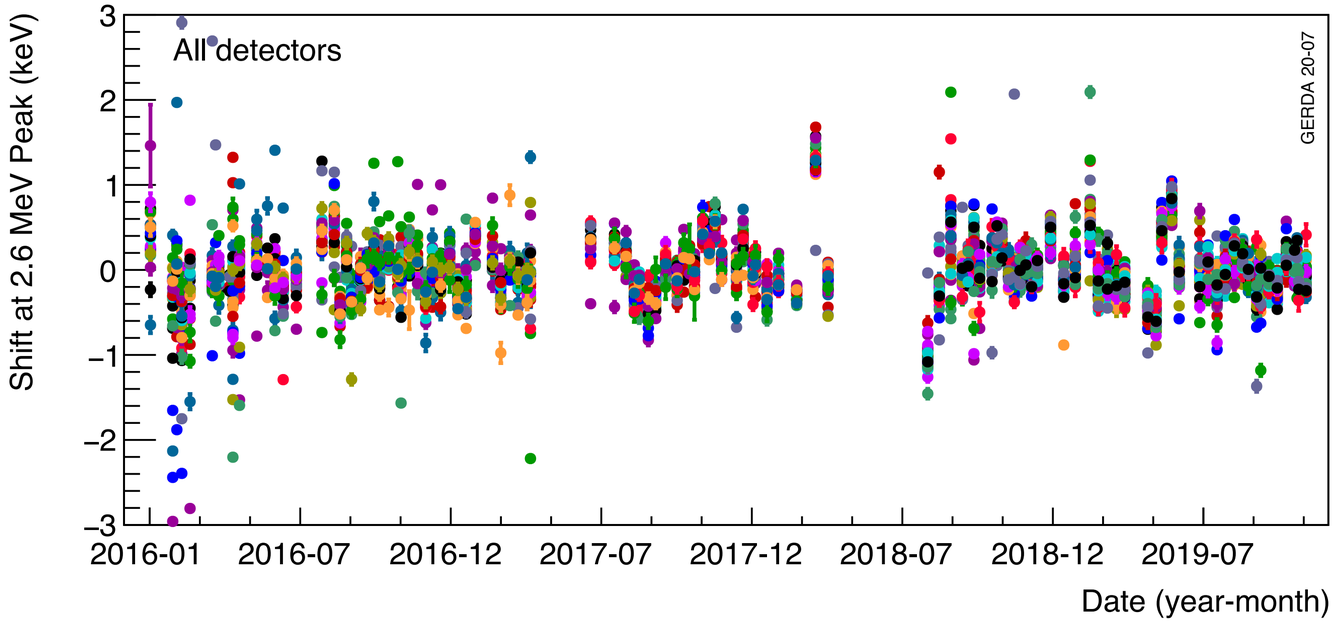
- Phase II duty cycle: 87.7%
- **103.7 kg yr** (127.2 kg yr with Phase I)
- Upgrade in 2018

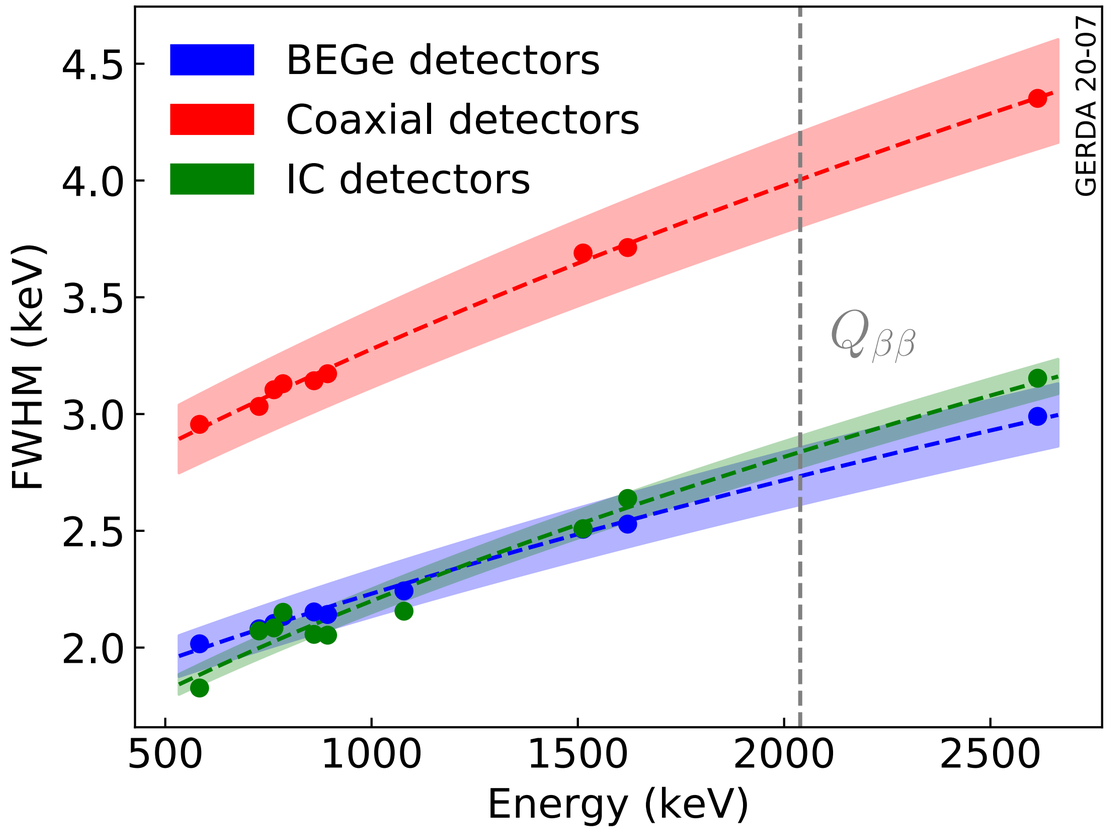
new fiber shroud



5 new inverted coaxial detectors

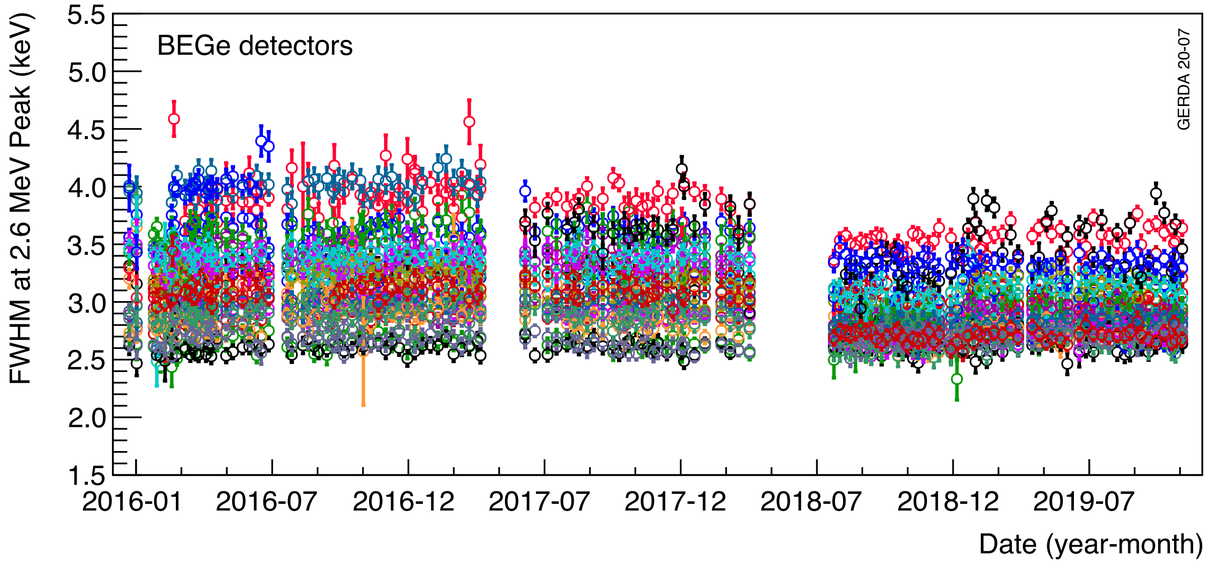
Performance on the energy scale

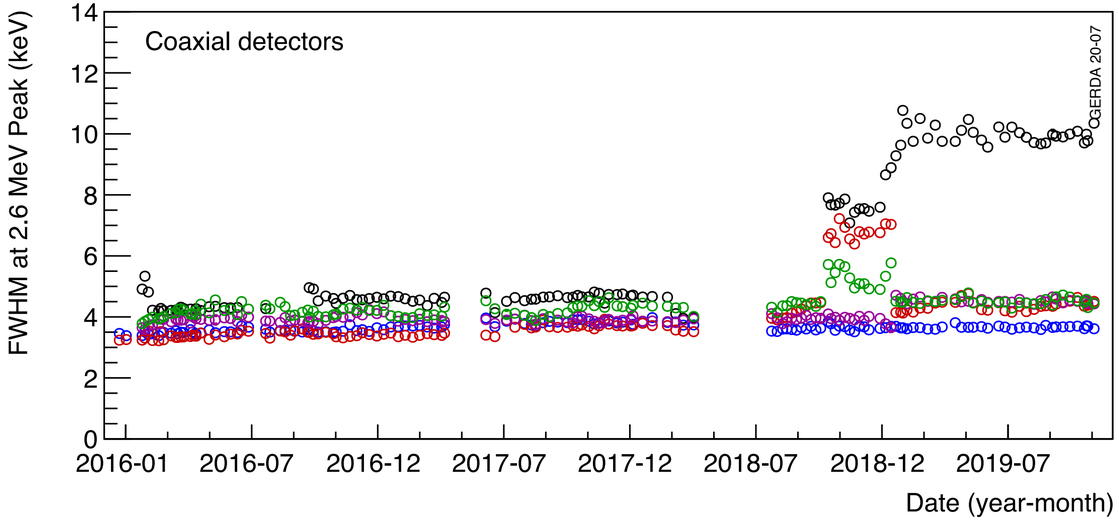


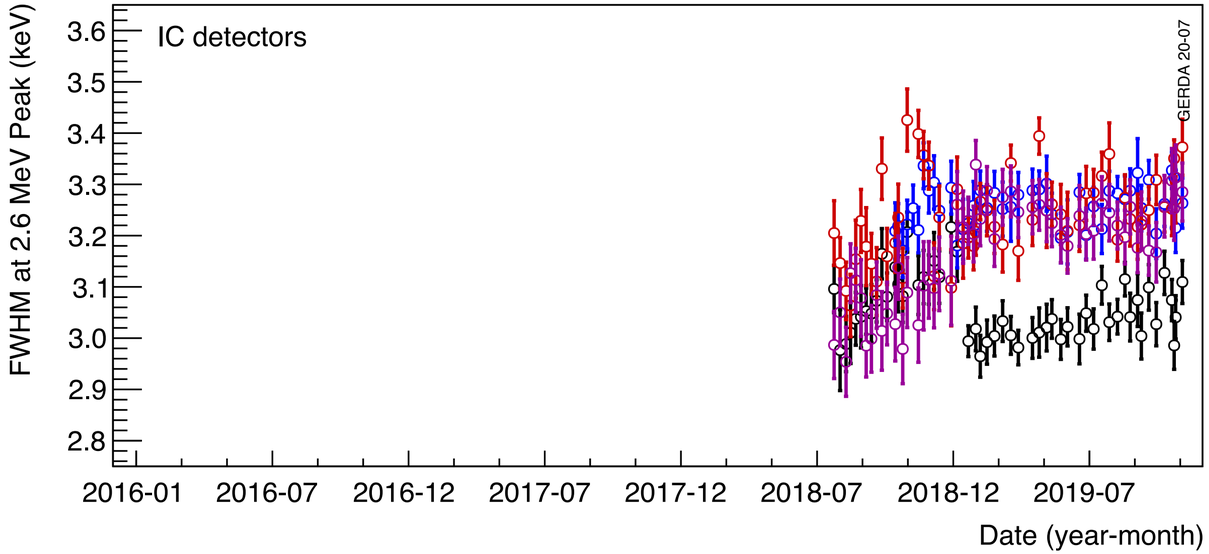


- Detectors calibrated weekly with ^{228}Th
- Energy shifts between calibrations < 1 keV
- Zero Area Cusp energy filter [*European Phys J C* 75 (2015), 255]

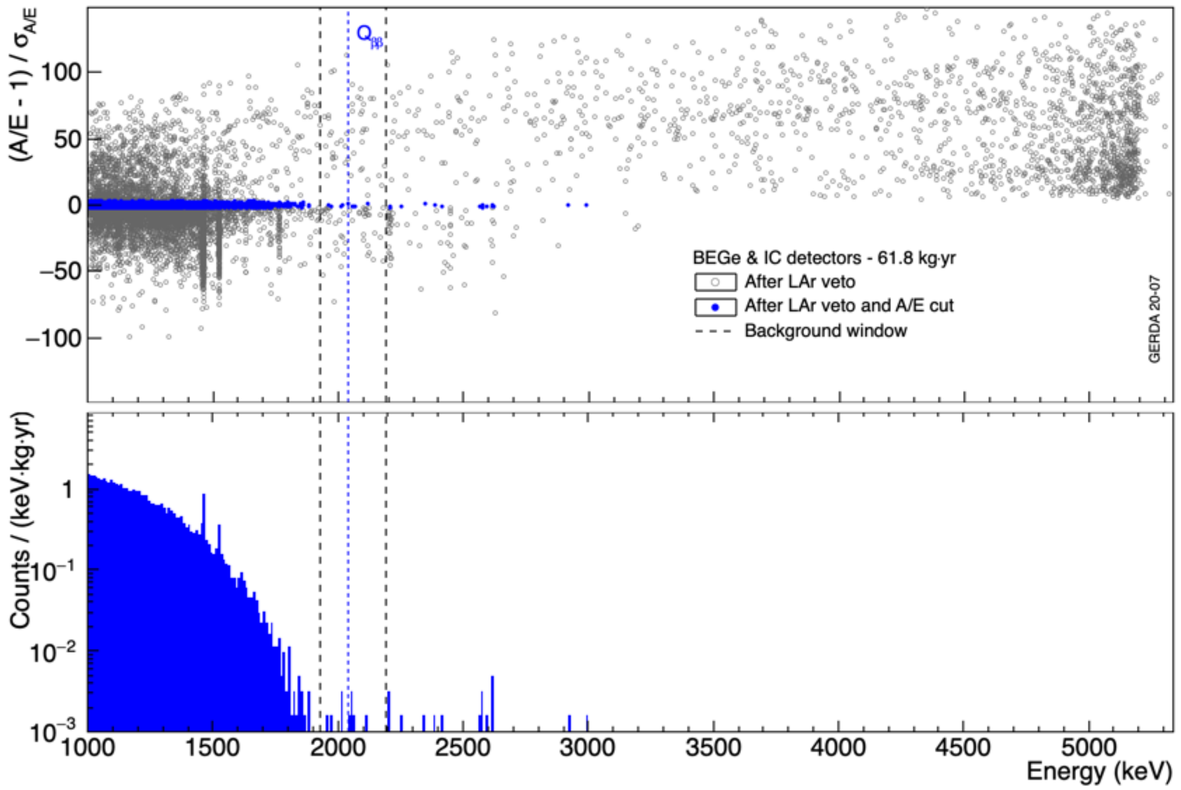
Resolution stability

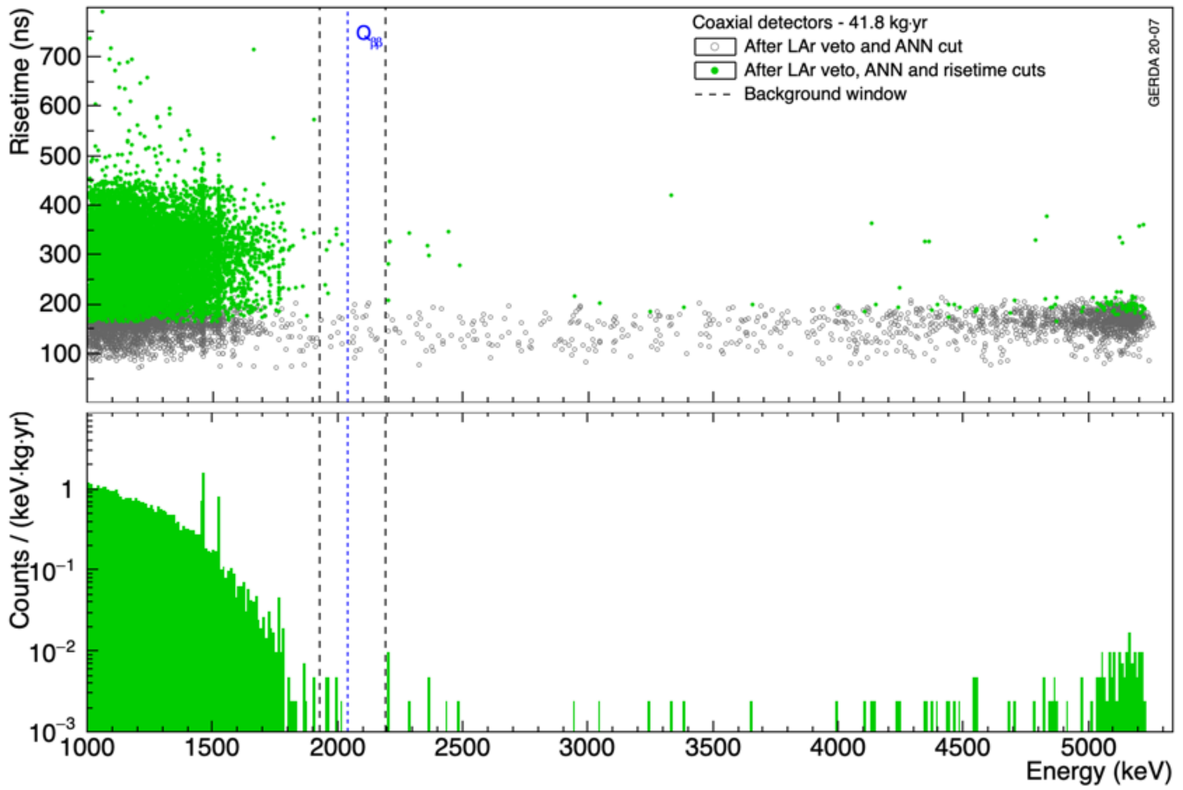




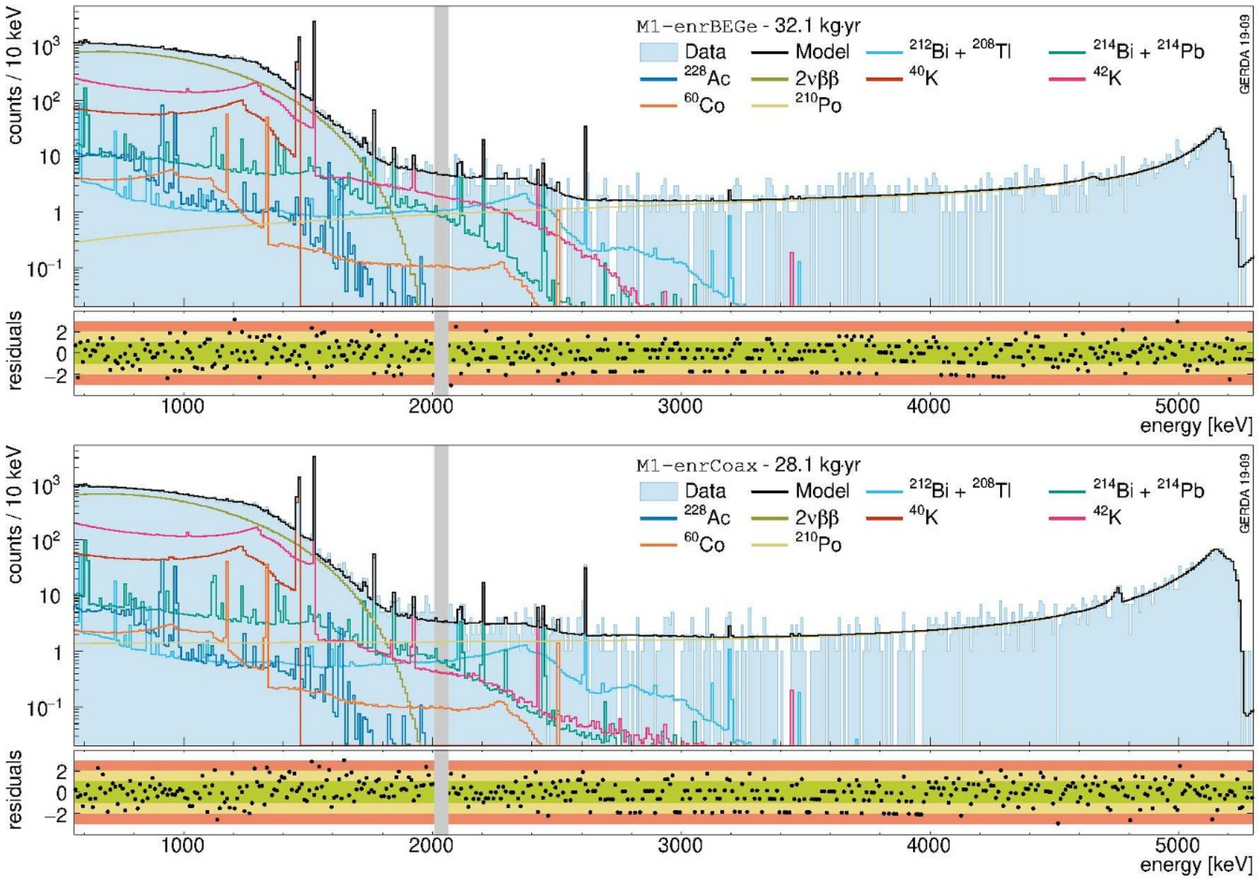


Details on PSD





Background Model



[GERDA, *J High Energy Phys*, **2020** (2020), no. 3, 139]