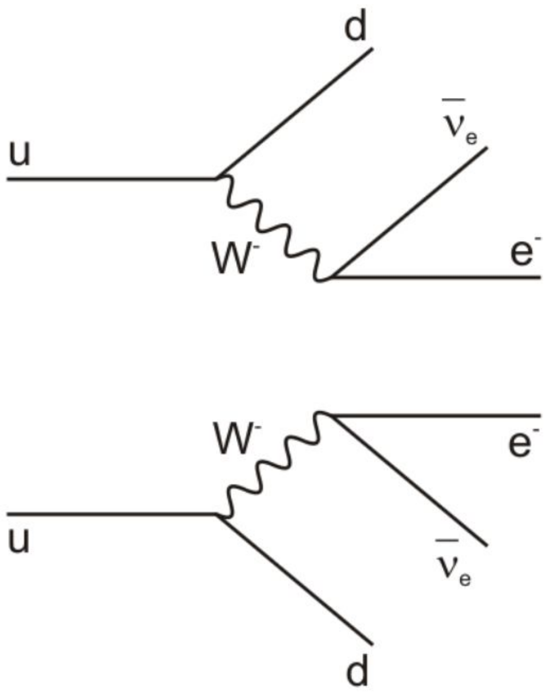
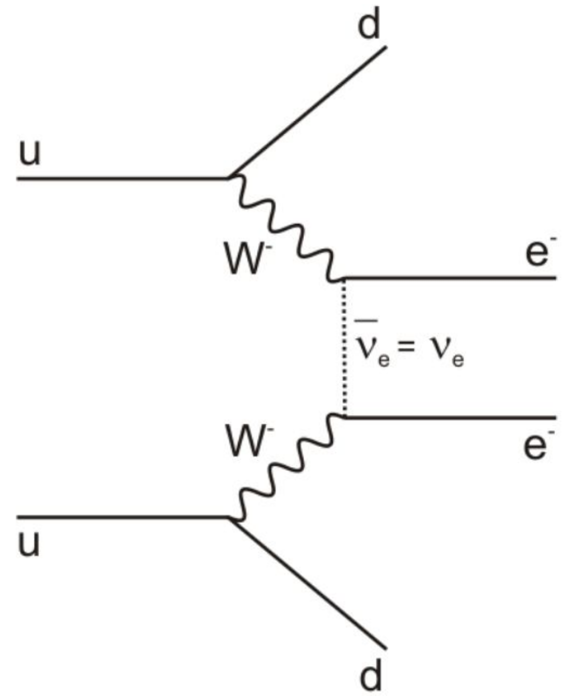
Results of the background-free search for neutrinoless double beta decay with GERDA and challenges of the LEGEND experiment

Mario Schwarz on behalf of the GERDA Collaboration

Low Radioactivity Techniques 2019
May 19 - 23

(Neutrinoless) double beta decay





2νββ

$T_{1/2}(^{76}Ge) = (1.926 +/- 0.094) \times 10^{21}$ yr

(Eur.Phys.J. C75 (2015) no.9, 416)

0νββ

$\Delta L = 2$

beyond standard model

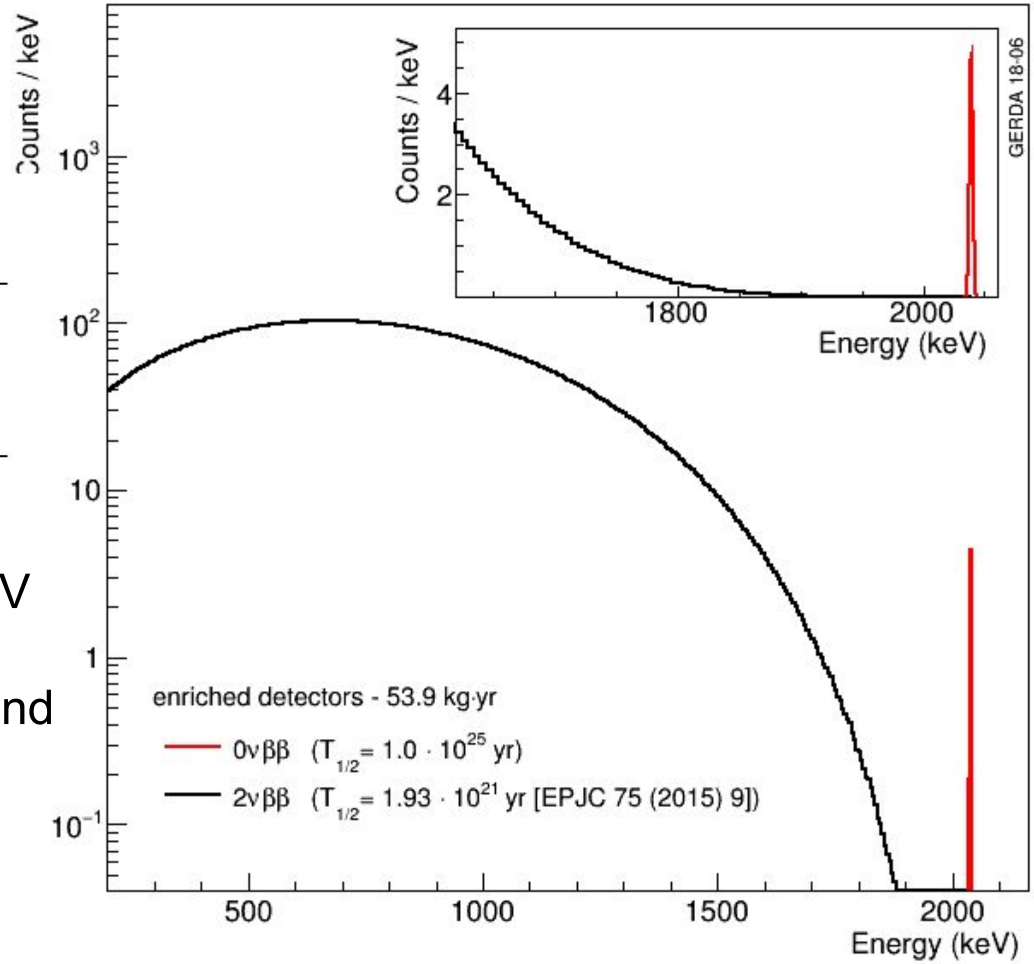
Search for 0νββ of ^{76}Ge using HPGe detectors

- source = detector
- radio-pure*

90% CL upper limits

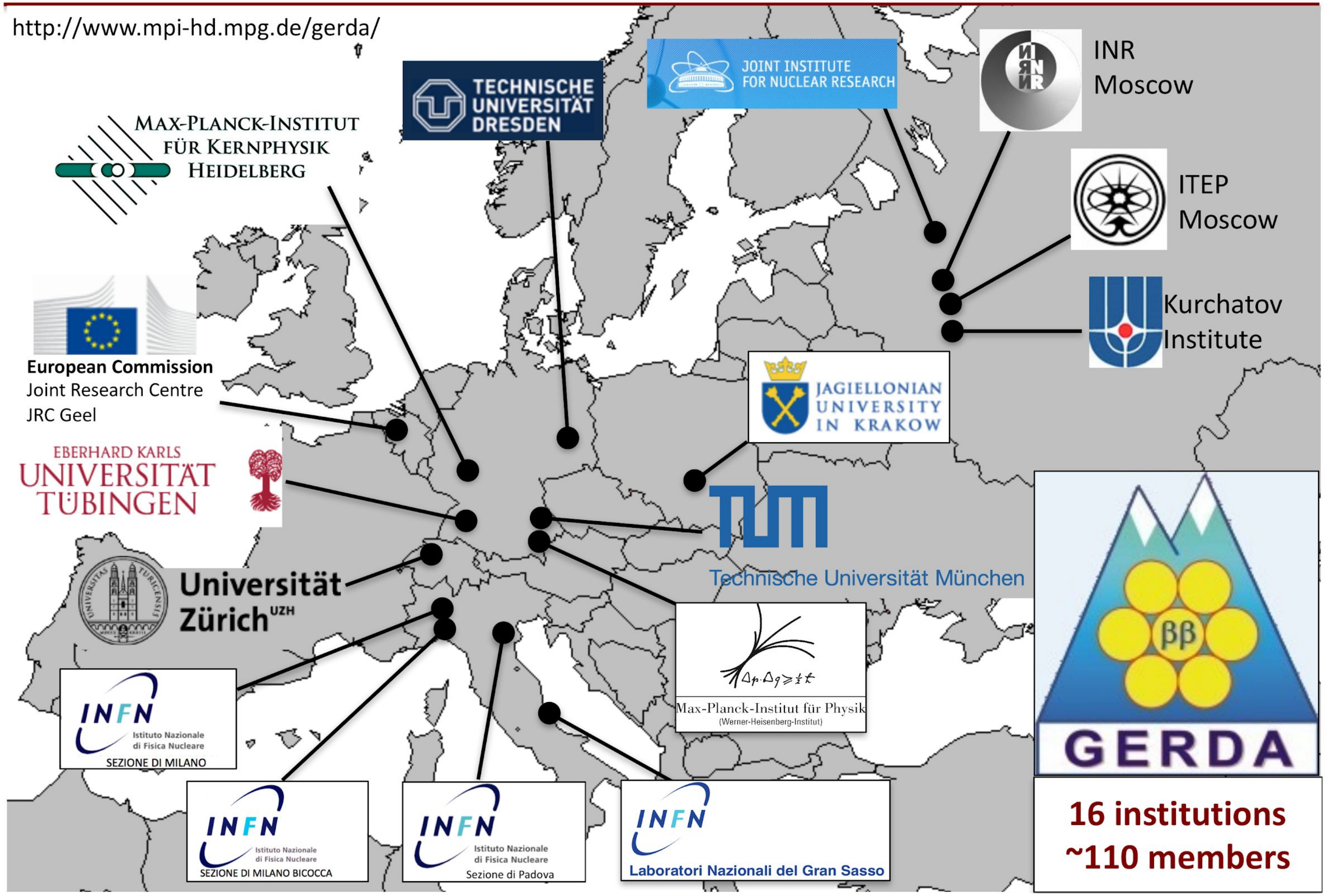
	contamination [g/g]	activity [nBq/kg]
^{226}Ra	$8.6 \cdot 10^{-23}$	3.1
^{227}Ac	$1.1 \cdot 10^{-24}$	3.0
^{228}Th	$1.0 \cdot 10^{-25}$	3.1

- excellent energy resolution: ~ 3 keV FWHM @ $Q_{\beta\beta}$ = 2039 keV
- high density
- topology information → background suppression



*Astropart.Phys. 91 (2017) 15-21

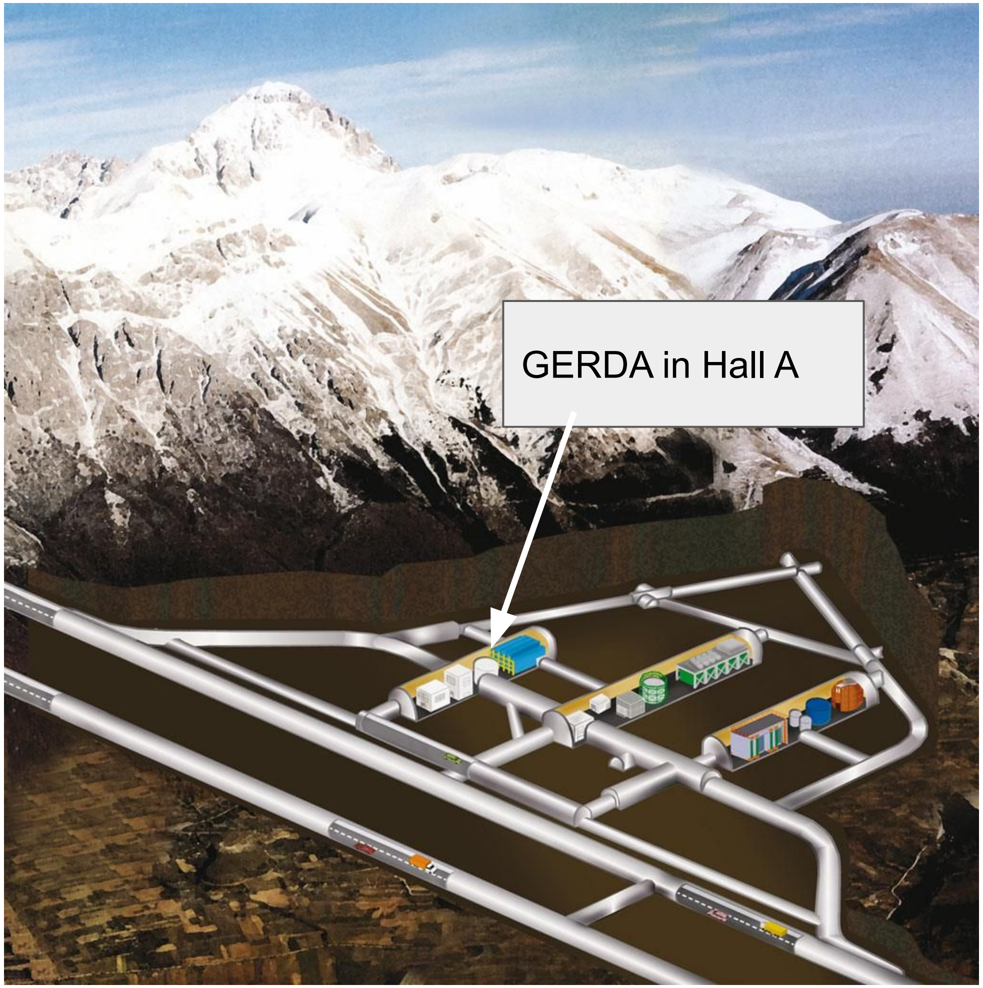
GERDA - GERmanium Detector Array



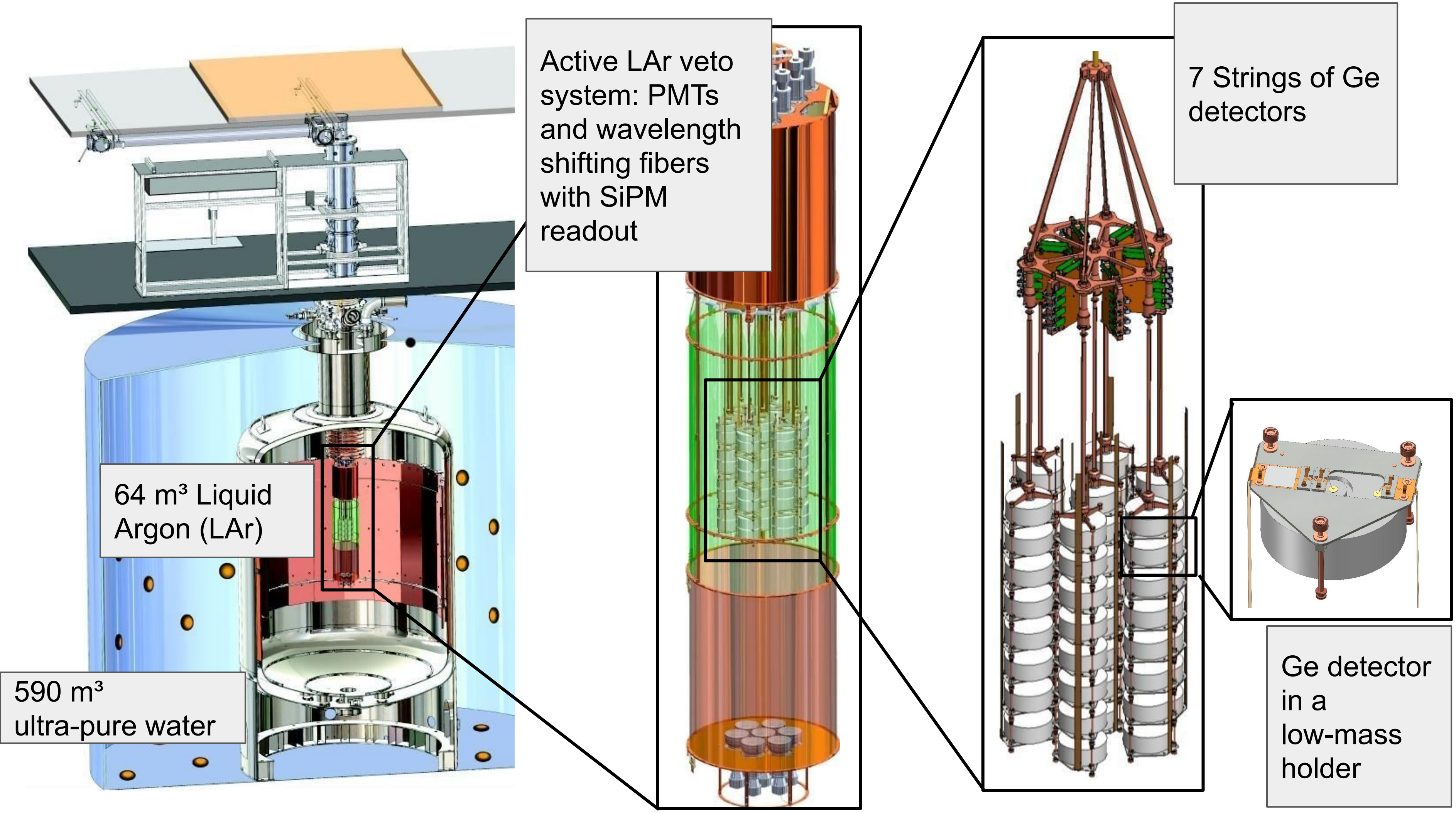
Overview of the GERDA experiment

- Located in the Laboratori Nazionali del Gran Sasso (LNGS) in Italy
- Shielded by 3500 m.w.e. of rock

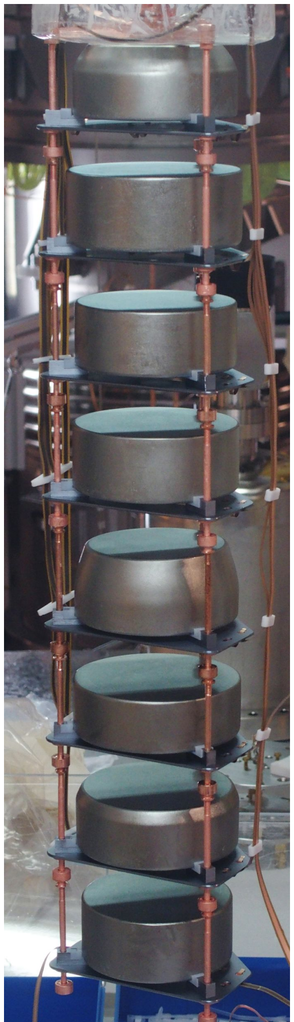
- GERDA Phase I: 2009 - 2013
- GERDA Phase II: 2015 - 2019
  - Upgrade Phase II+ in 2018

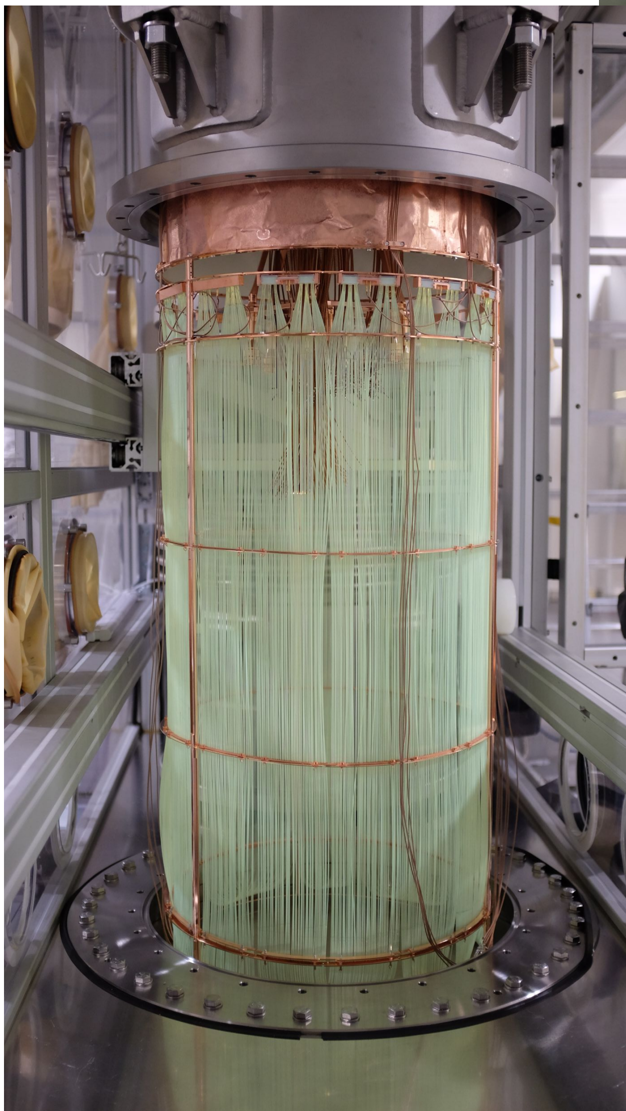


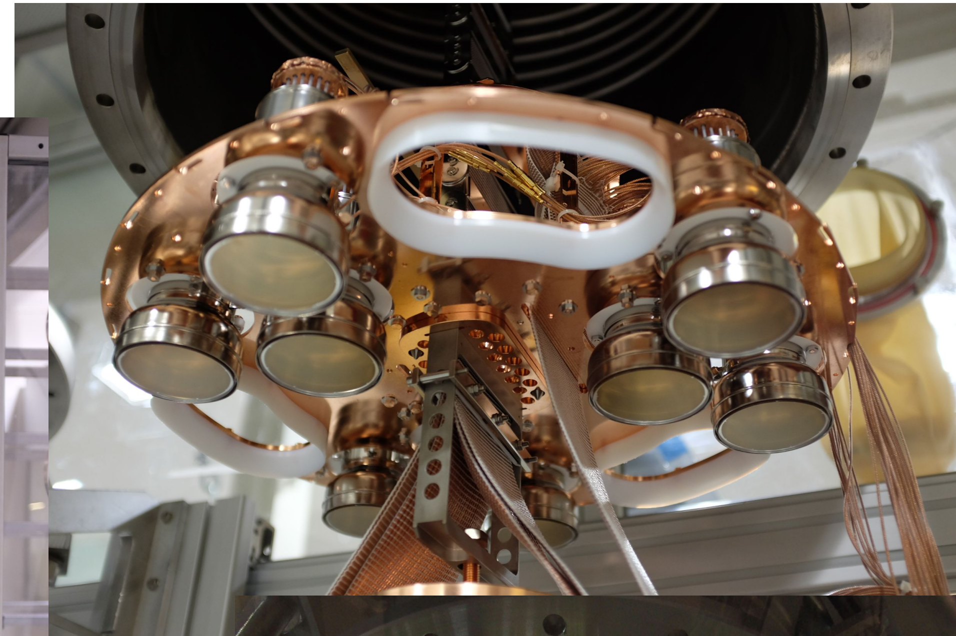
Overview GERDA Phase II



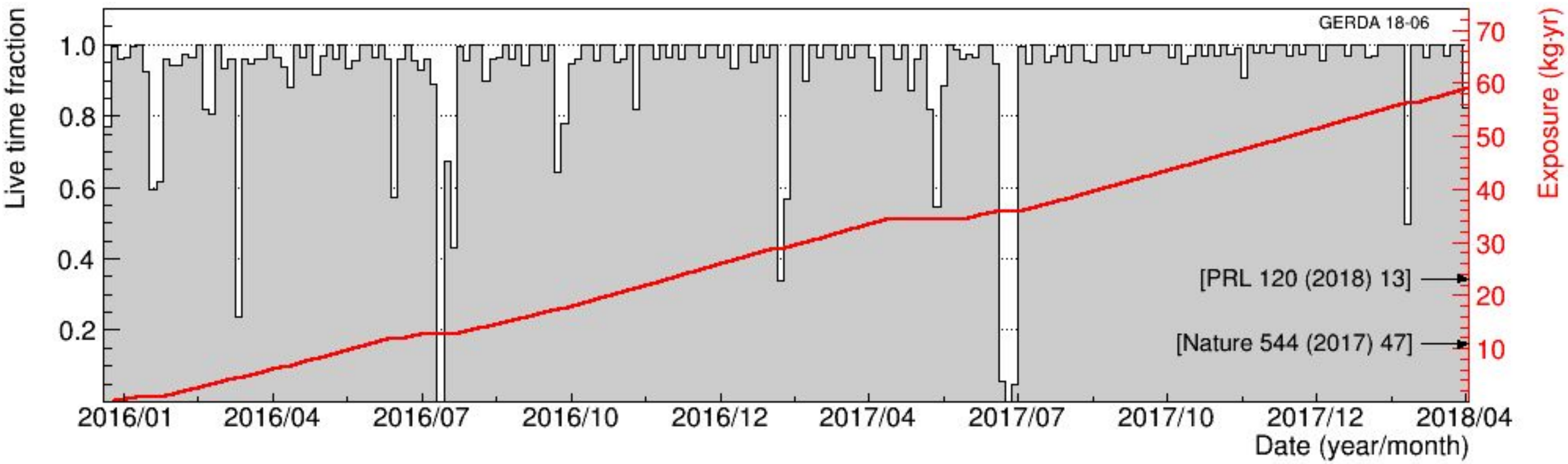
GERDA Phase II





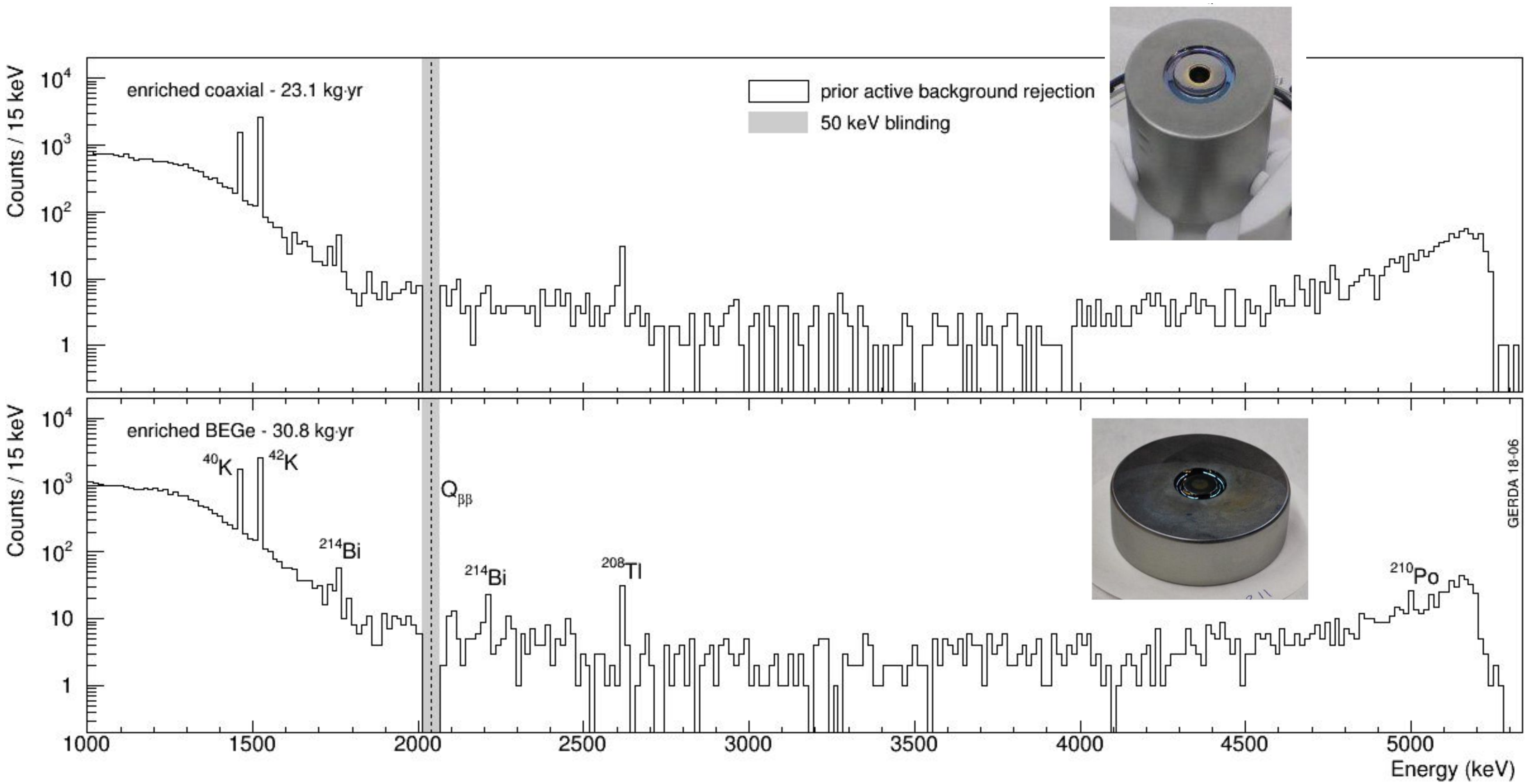


Phase II data taking



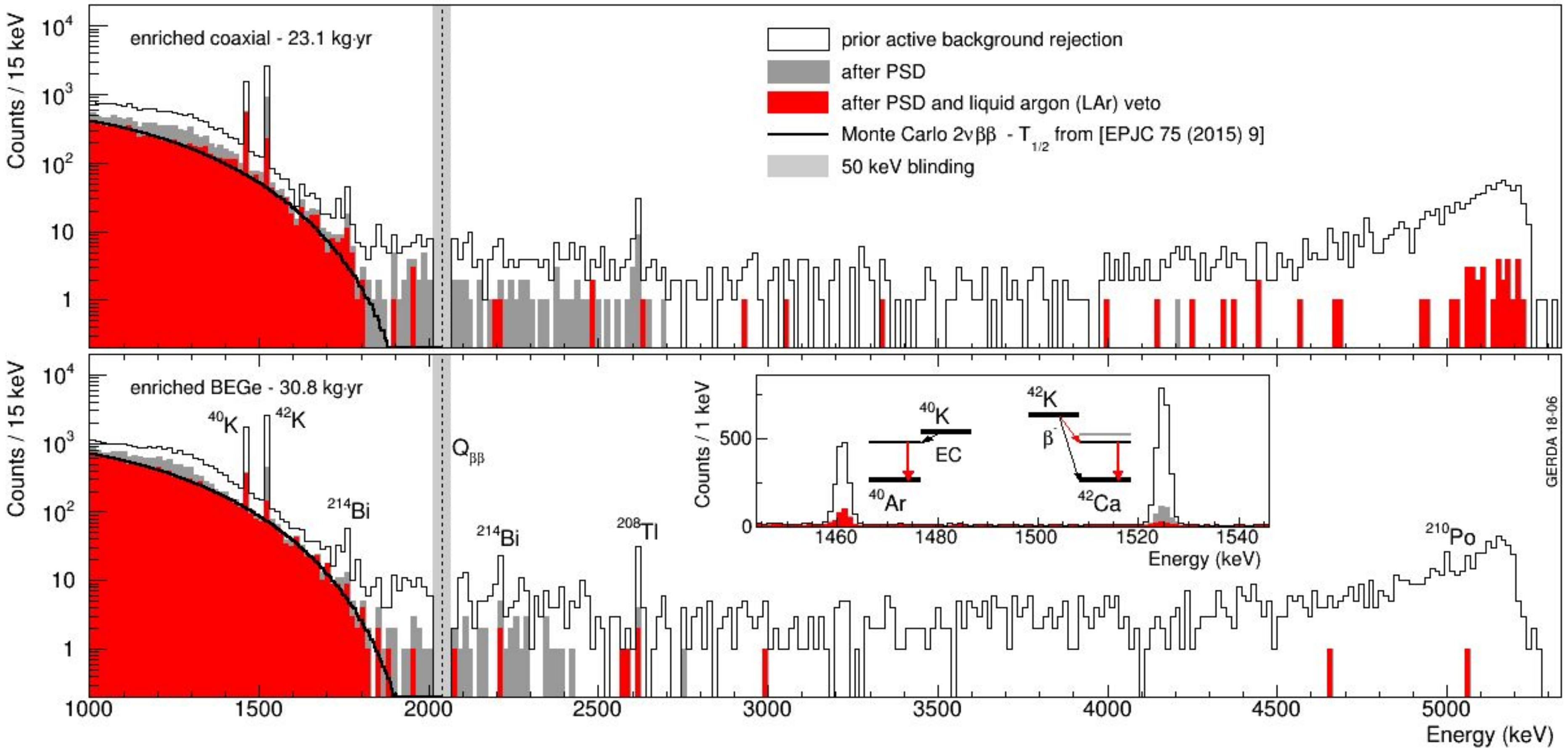
- Phase II data taking: December 2015 to April 2018 (before upgrade)
  - 834.8 d live time; 74.7% used for analysis
- 35.6 kg enriched detector mass
- 58.9 kg yr exposure for Phase II
  - Data taking resumed as Phase II+
- 100 kg yr reached this autumn

Phase II data taking

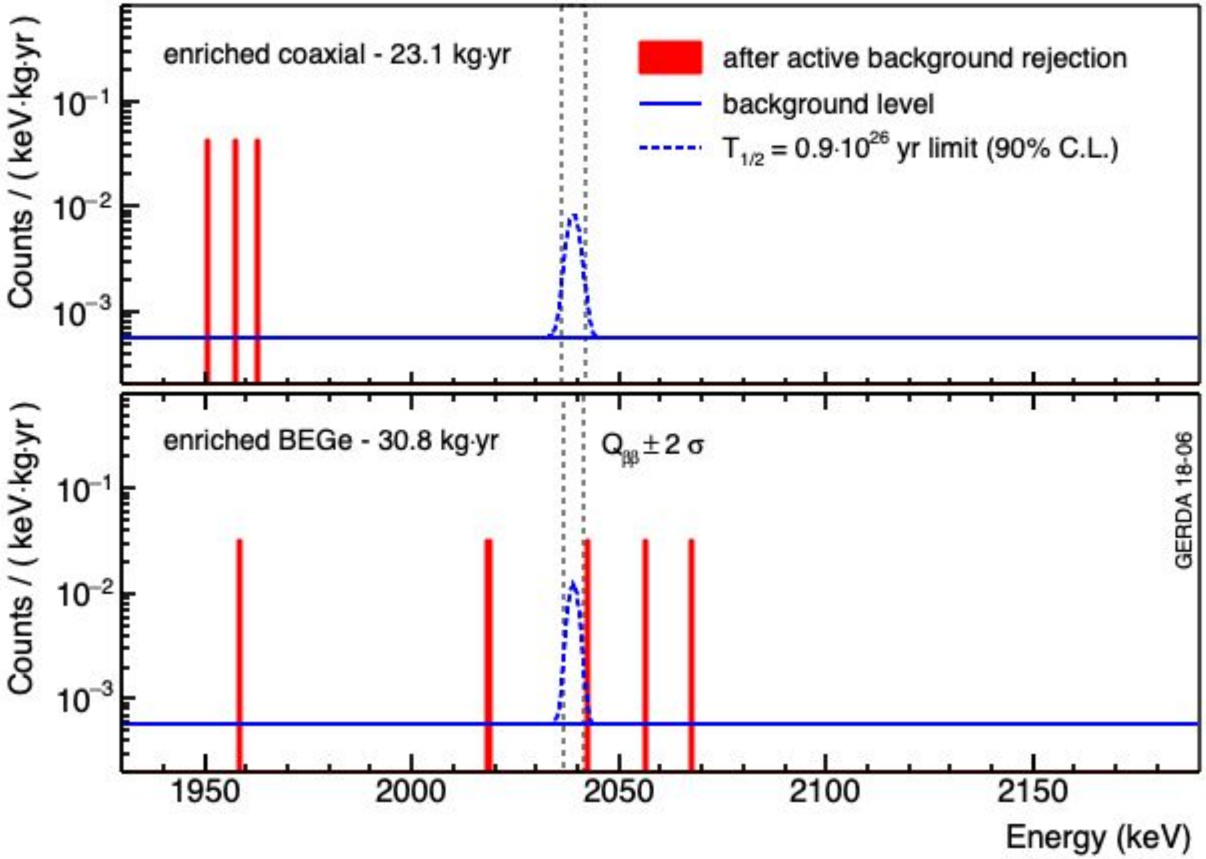


Spectra before active background rejection

Active background suppression in GERDA



0νββ analysis



Phase II:

Background in ROI:
~ 6×10^{-4} cts / (keV kg yr)

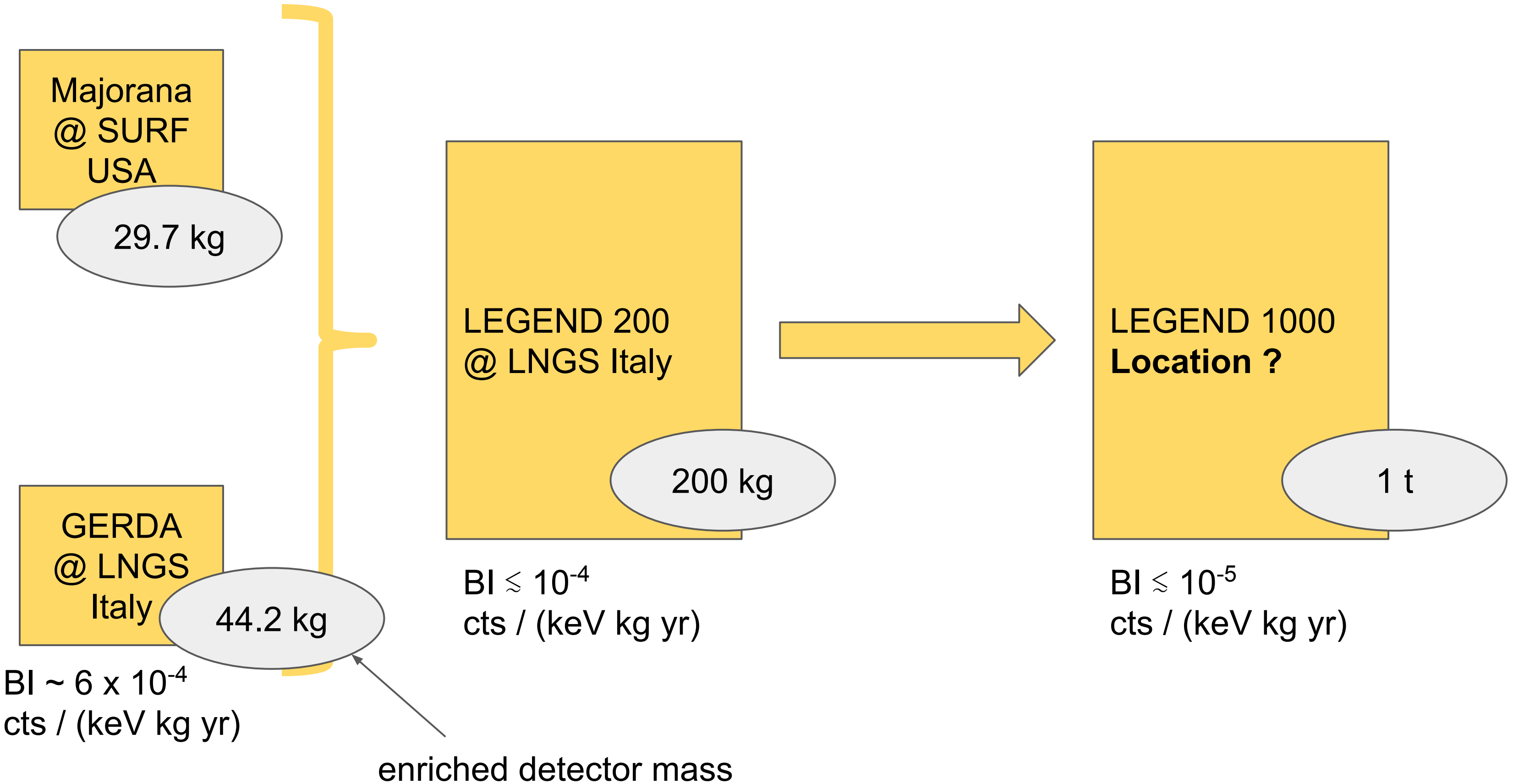
Together with Phase I data
(combined exposure 82.4 kg yr):

Sensitivity: 1.1×10^{26} yr

$T_{1/2} > 0.9 \times 10^{26}$ yr (Frequentist)

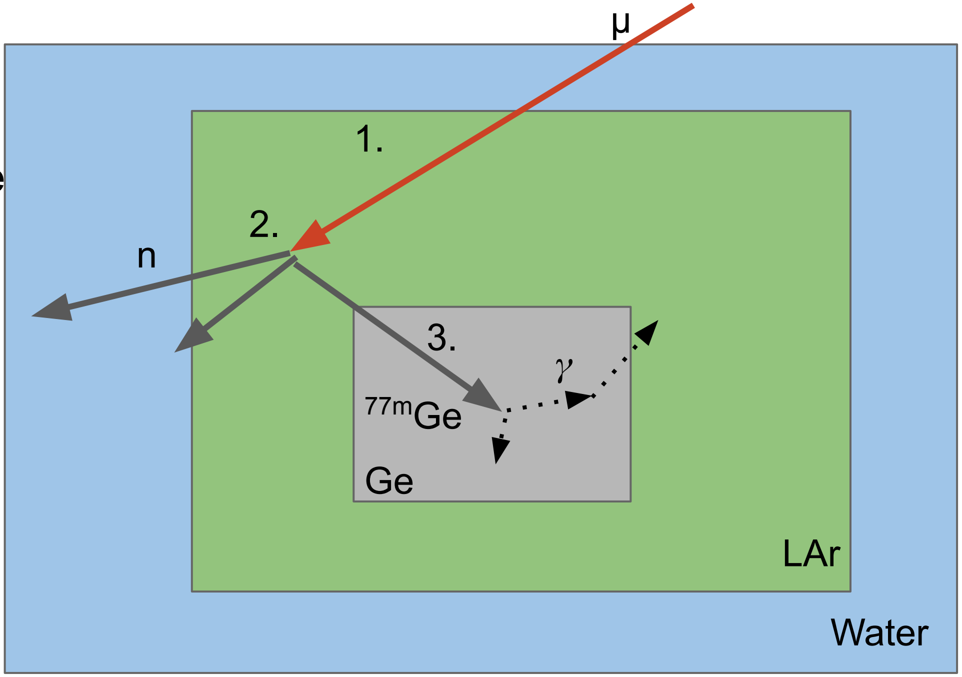
(90% C.L.)

The Large Enriched Germanium Experiment for Neutrinoless ββ decay - LEGEND



Topology of μ induced events with ^{77m}Ge production

1. A cosmic muon passes through the setup creating signals in water and LAr channels
2. Neutrons are produced; usually $n > 1$
3. Neutron capture on ^{76}Ge producing ^{77m}Ge & prompt gammas



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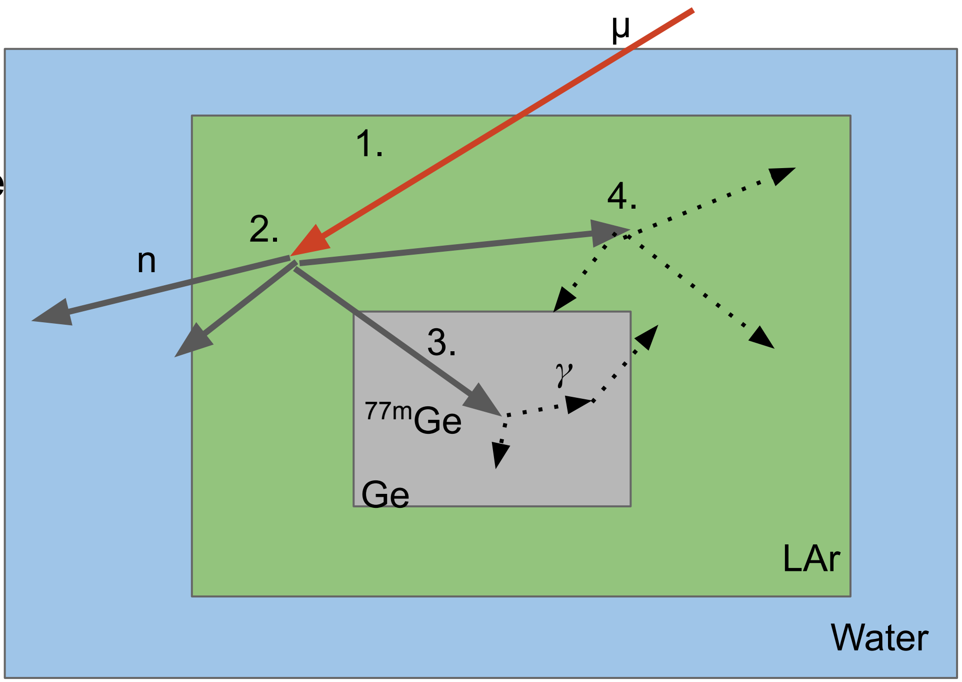

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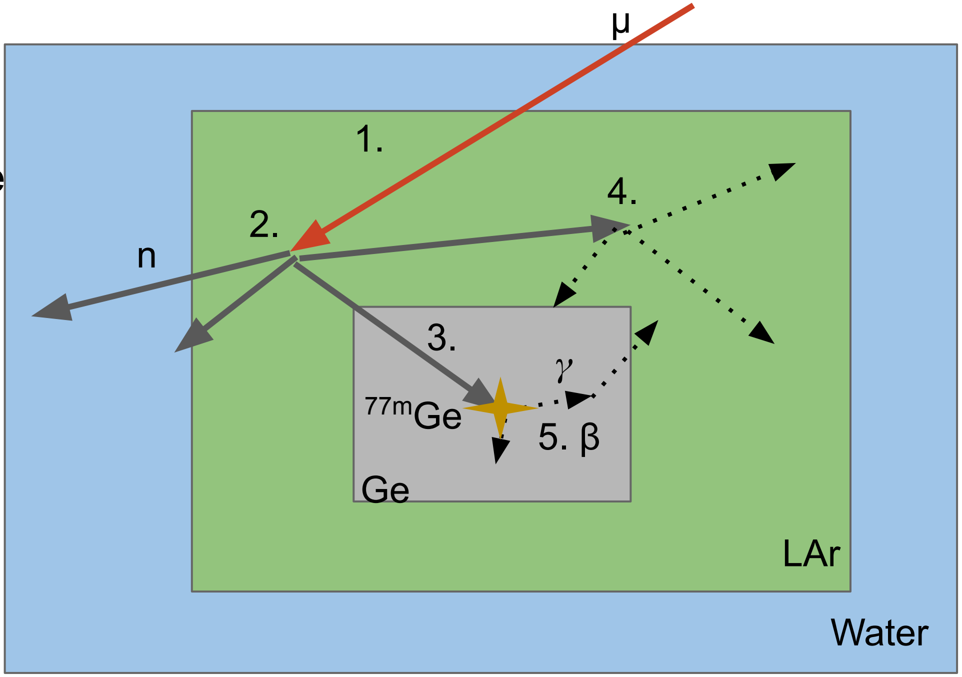

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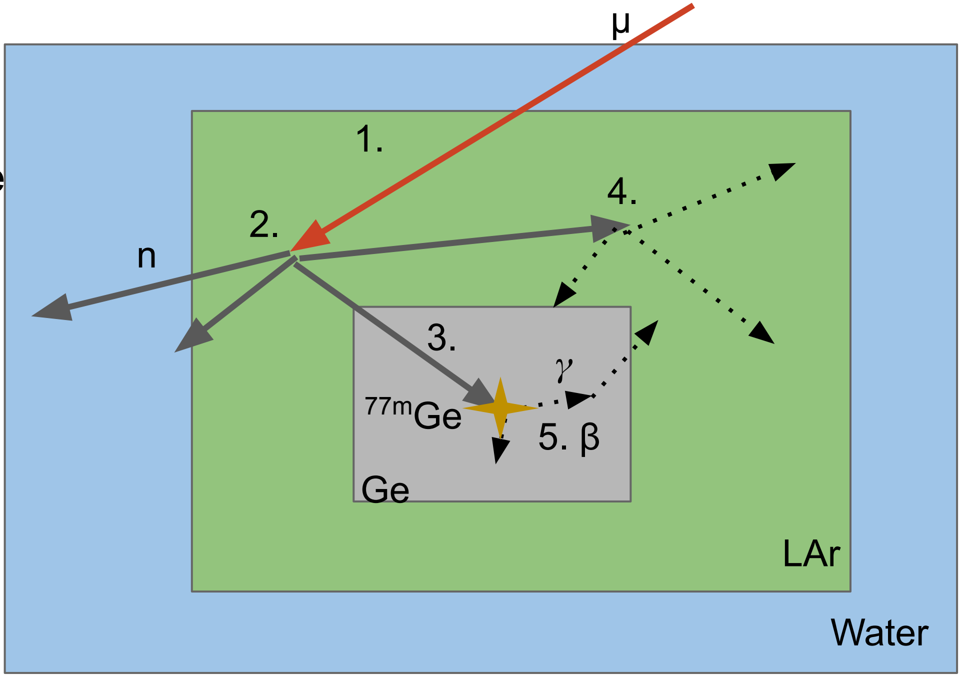
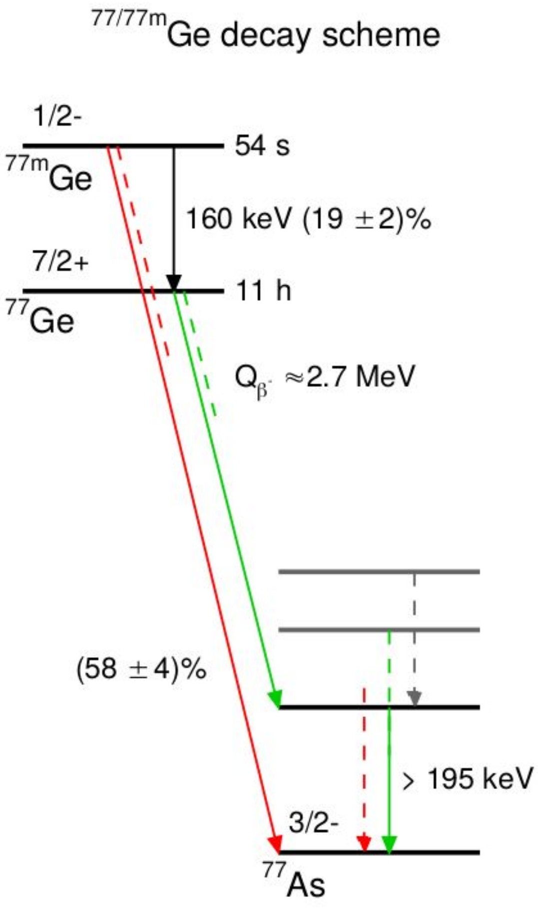


<u>Plan</u>: Use the signal structure of muon + neutron production events to tag the production of ^{77m}Ge → remove several half-lives of ^{77m}Ge to reduce background

Backgrounds due to μ-induced isotope production

- Geant4-simulation based on GERDA geometry done*
- Background contribution with analysis as done in GERDA:
  - $(1.5 \pm 0.2) \times 10^{-6}$ cts/(keV kg yr) for ^{77}Ge
  - $(1.8 \pm 0.4) \times 10^{-5}$ cts/(keV kg yr) for ^{77m}Ge
- Using delayed tagging to reduce ^{77m}Ge background
  - Suppression of factor ≳ 10 possible
  - Important input for location selection for LEGEND-1000
- Verify simulation using LEGEND-200
  - Expect ~ 200 $^{77(m)}$Ge nuclei in 1 t yr of LEGEND-200



*Eur.Phys.J. C78 (2018) no.7, 597

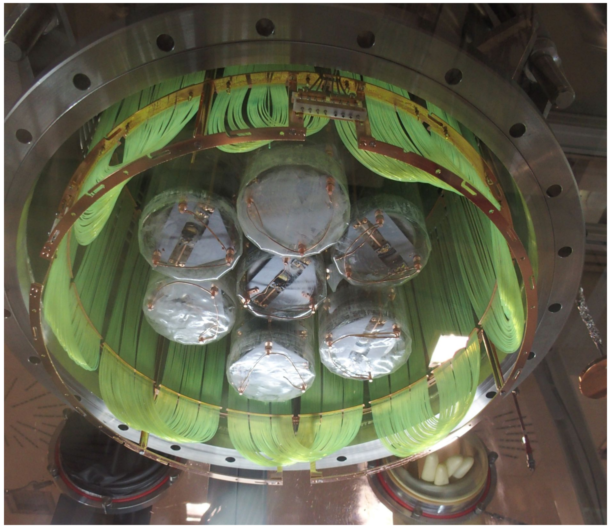
Summary

- GERDA Phase II: BI 6 x 10^{-4} cts / (keV kg yr) and sensitivity 1.1 x 10^{26} yr reached.
- Exposure of 58.9 kg yr acquired until April 2018, data taing ongoing

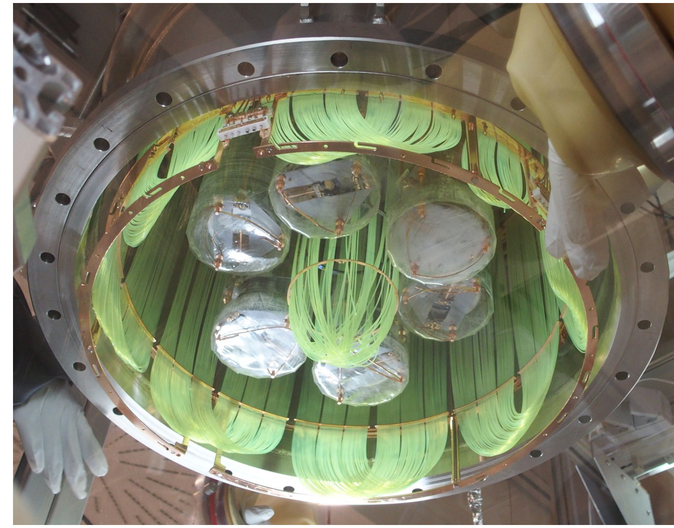
- Investigated cosmogenic ^{77m}Ge as important background contribution for LEGEND-1000
- Ability to study this and other delayed backgrounds in LEGEND-200

Backup slides

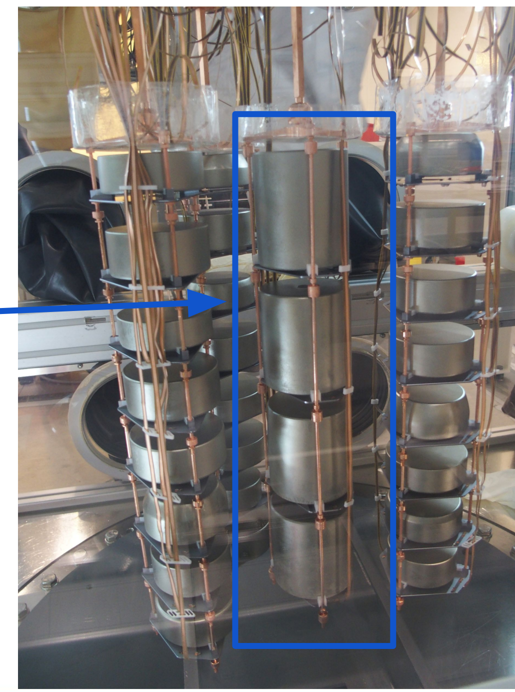
GERDA Phase II+



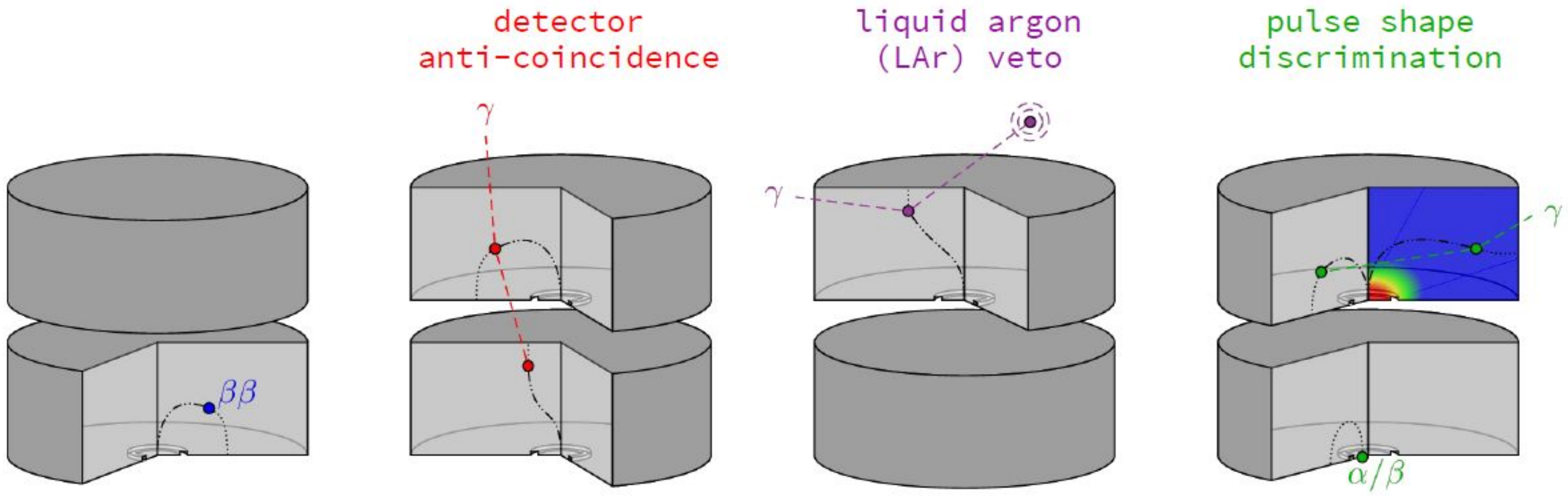
Introduced central fiber shroud & increased density of outer shroud



Introduced 5 inverted coaxial point-contact detectors (4 of them in central string, shown here)

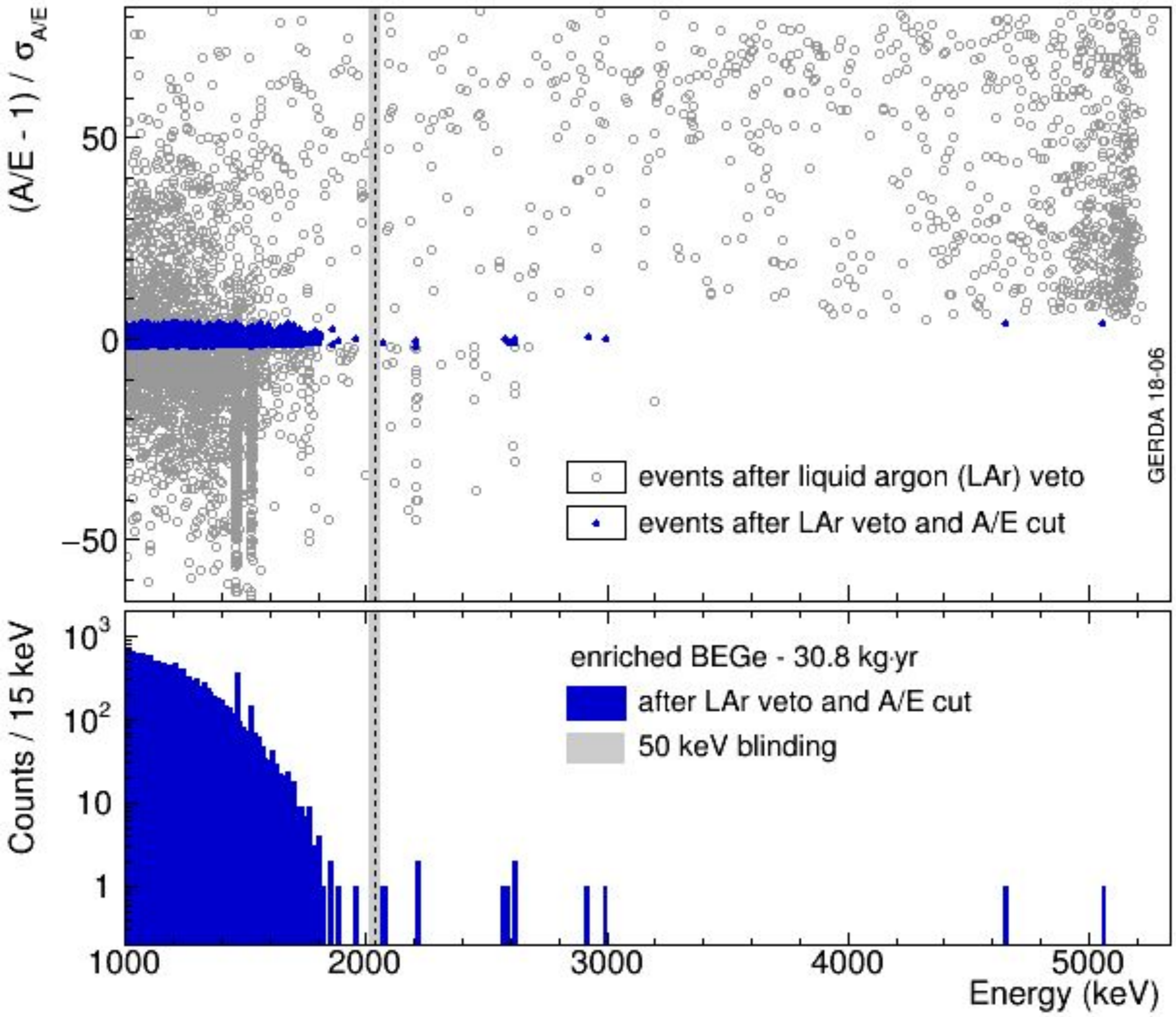


Active background suppression in GERDA



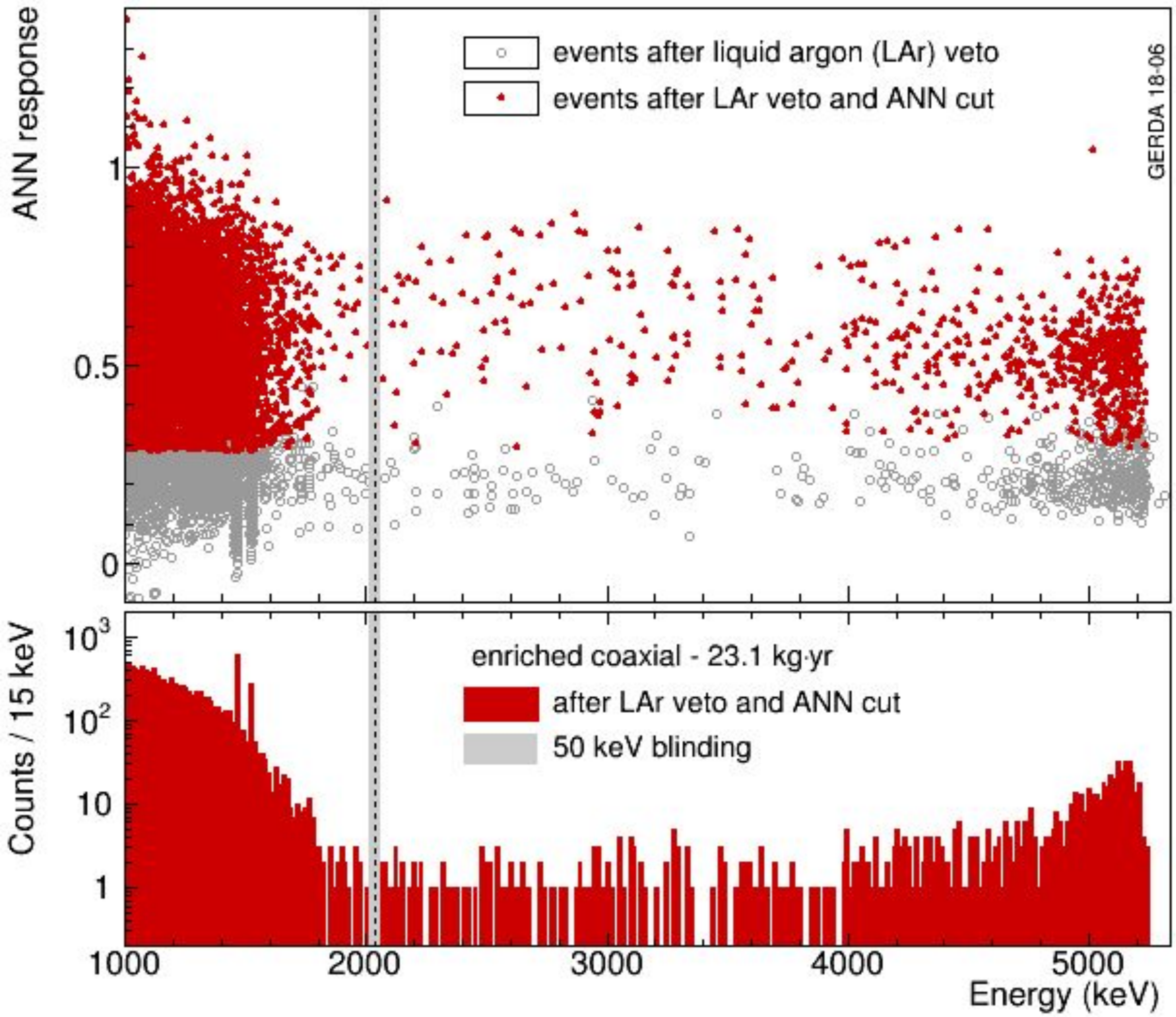
Thanks to Ch. Wiesinger

A/E Cut BEGe



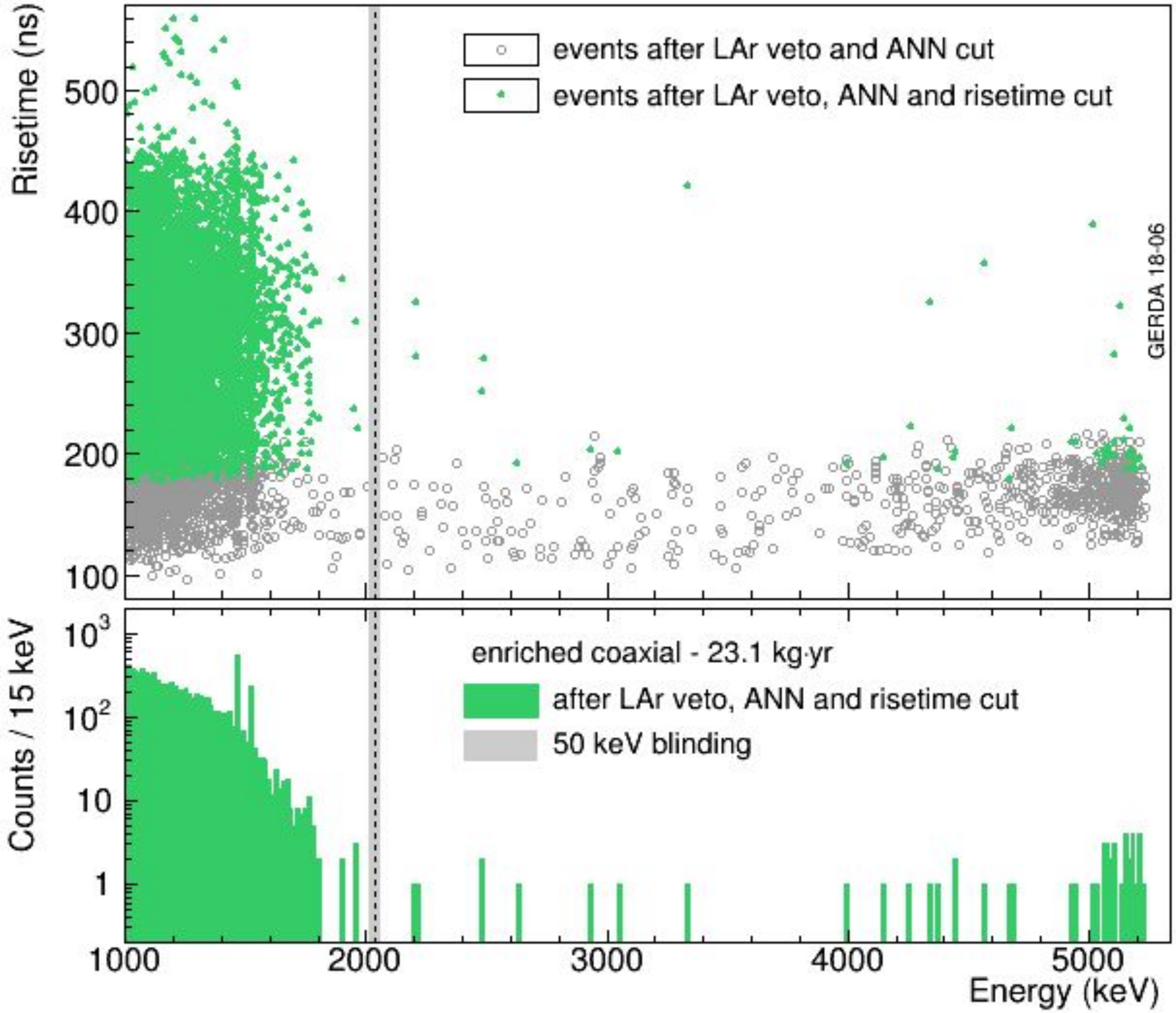
(A/E - 1) / σ_A/E
50
0
−50
events after liquid argon (LAr) veto
events after LAr veto and A/E cut
GERDA 18-06
Counts / 15 keV
10³
10²
10
1
enriched BEGe - 30.8 kg·yr
after LAr veto and A/E cut
50 keV blinding
1000
2000
3000
4000
5000
Energy (keV)

ANN Coax

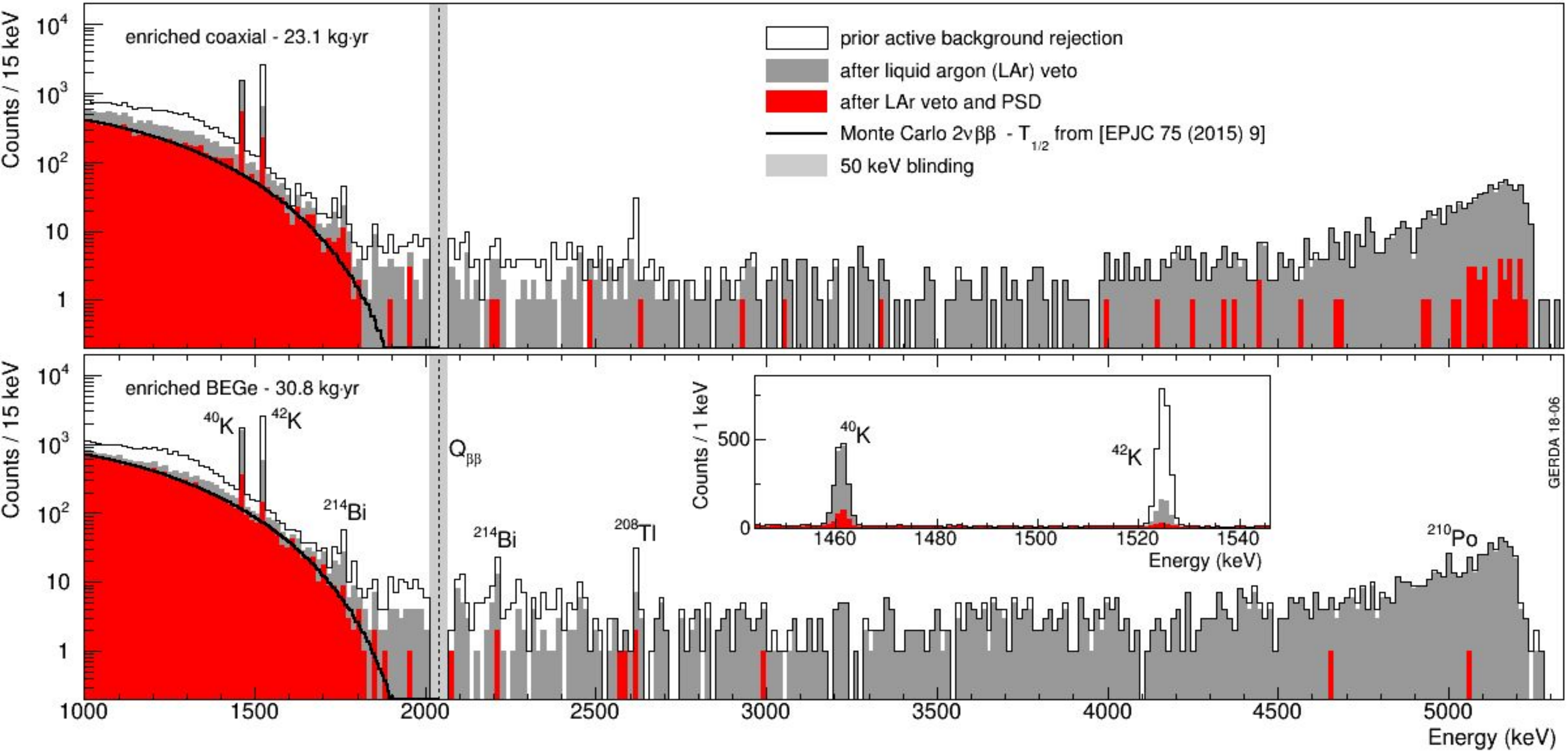


ANN response
events after liquid argon (LAr) veto
events after LAr veto and ANN cut
GERDA 18-06
0
0.5
1
Counts / 15 keV
enriched coaxial - 23.1 kg·yr
after LAr veto and ANN cut
50 keV blinding
1
10
10^2
10^3
1000
2000
3000
4000
5000
Energy (keV)

Risetime Coax

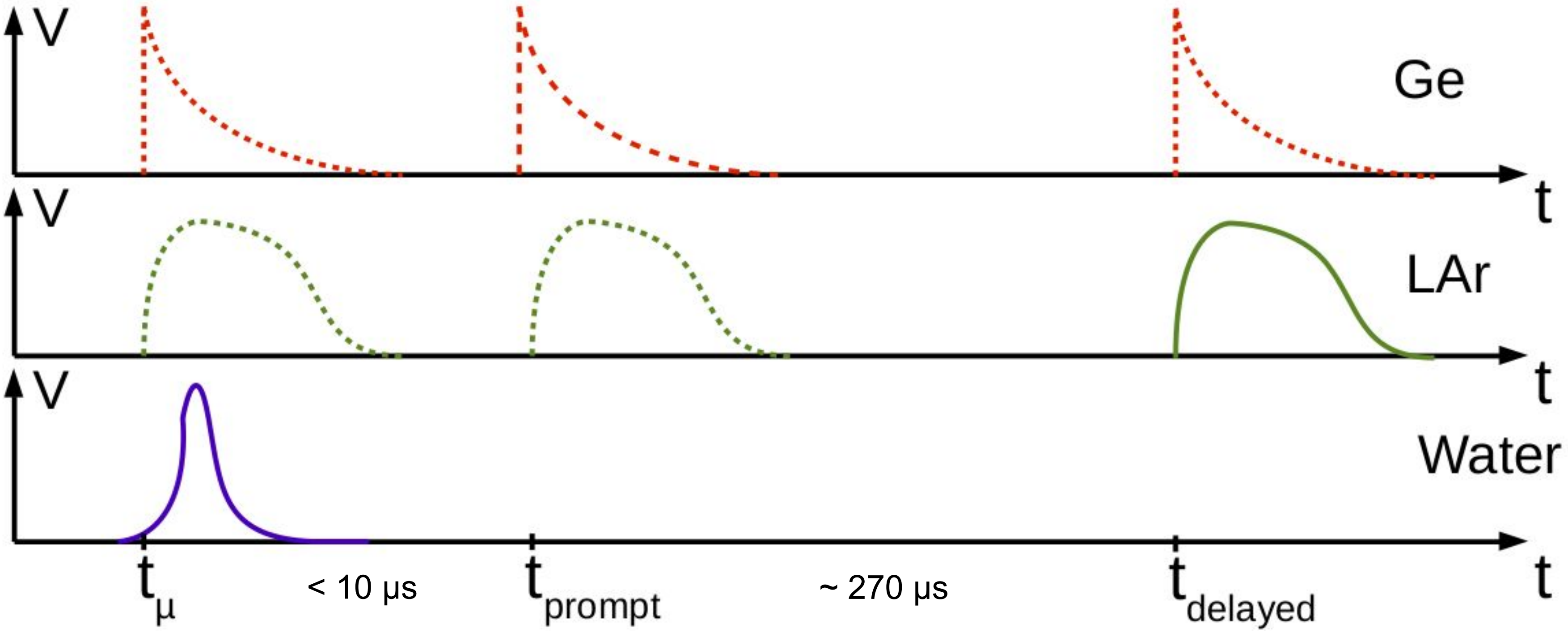


Active background suppression in GERDA



Signal structure of ^{77m}Ge production events

- Signal structure of an example event
- Dashed lines indicate missed signals



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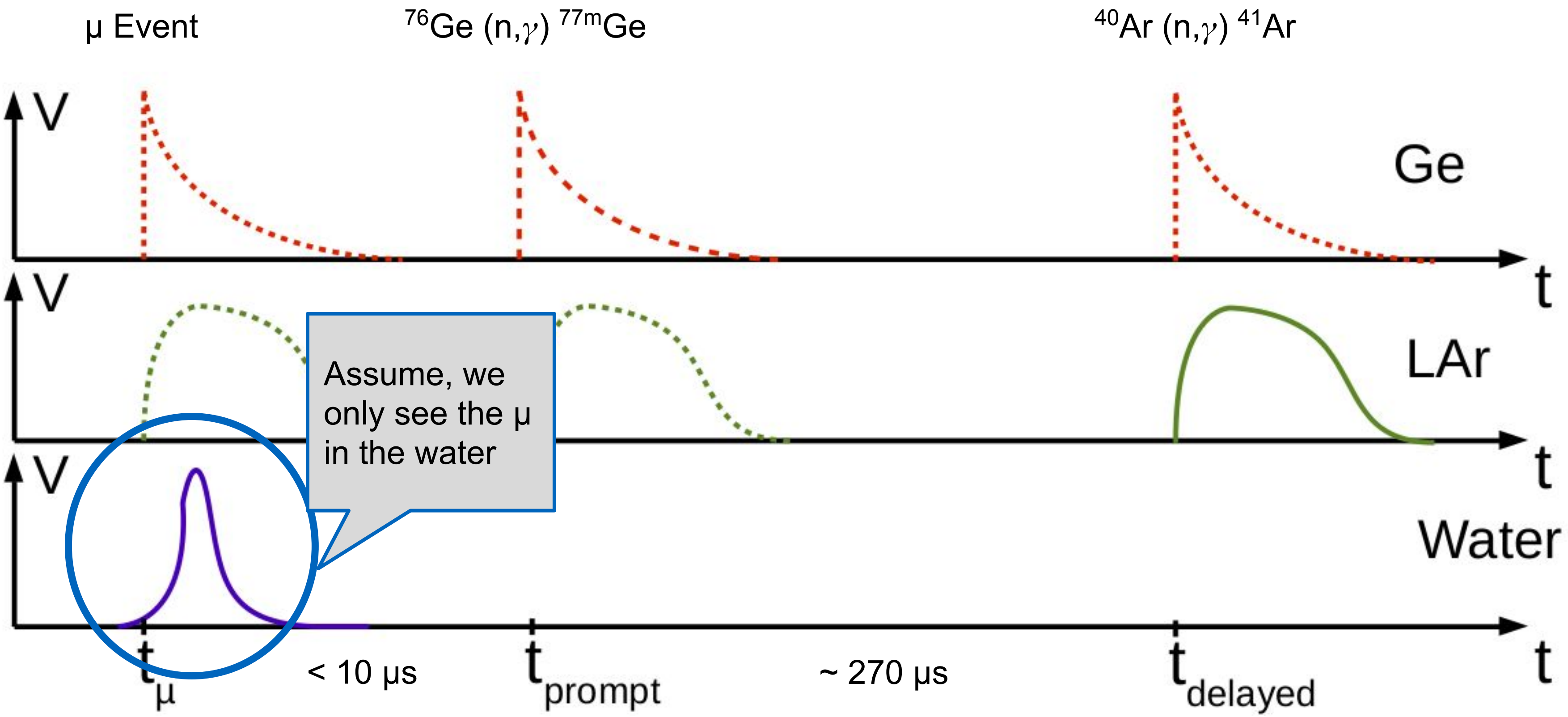

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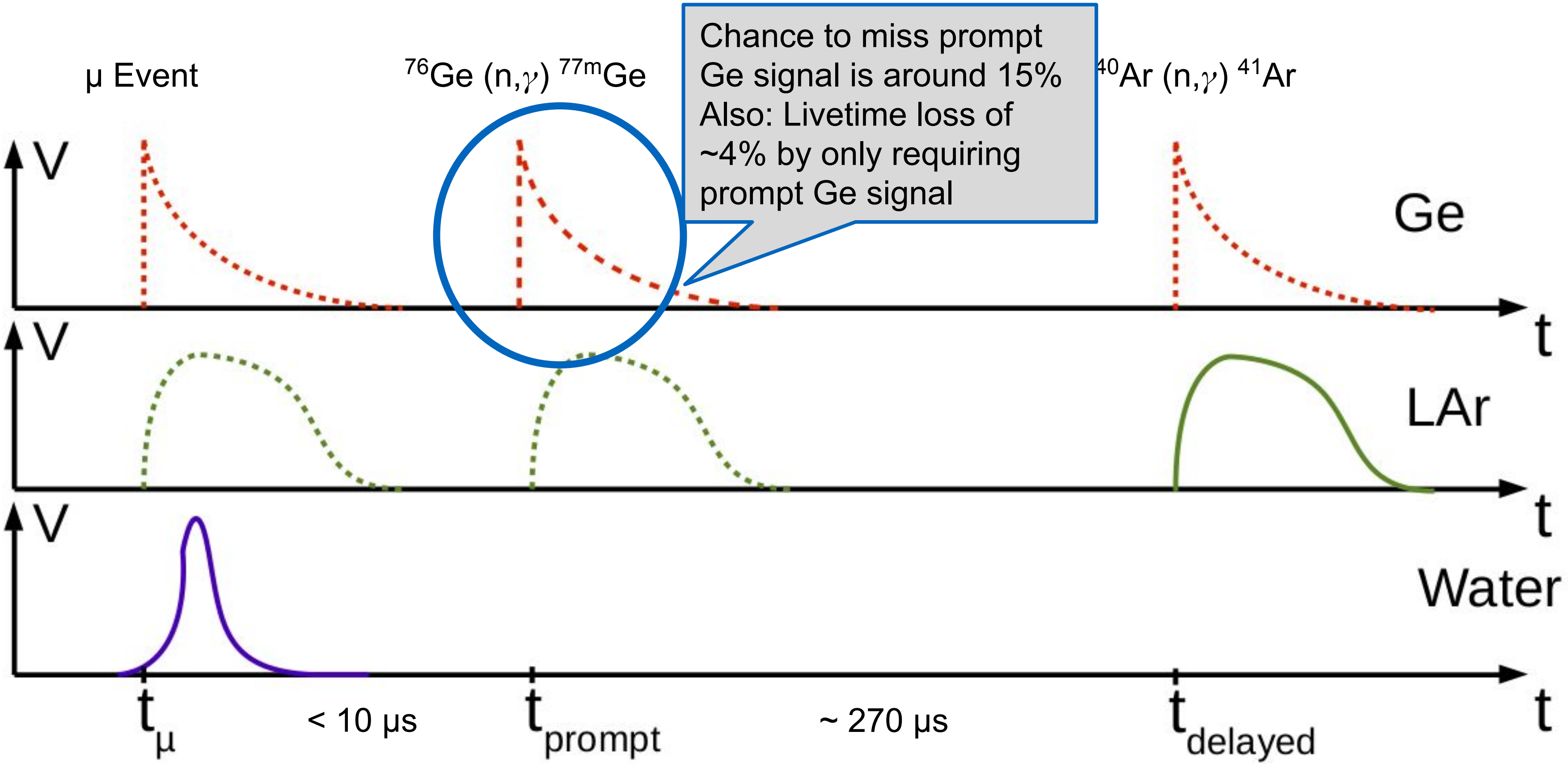

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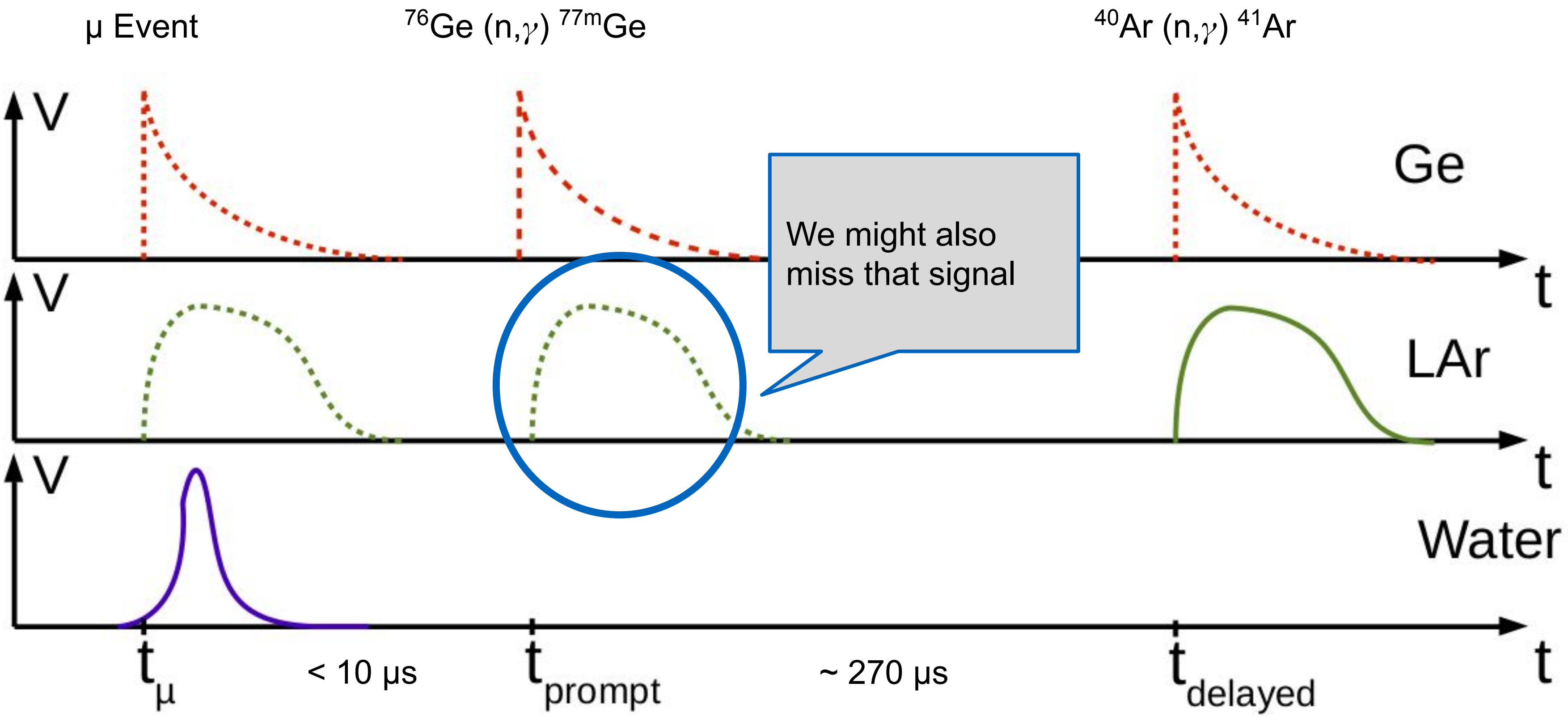

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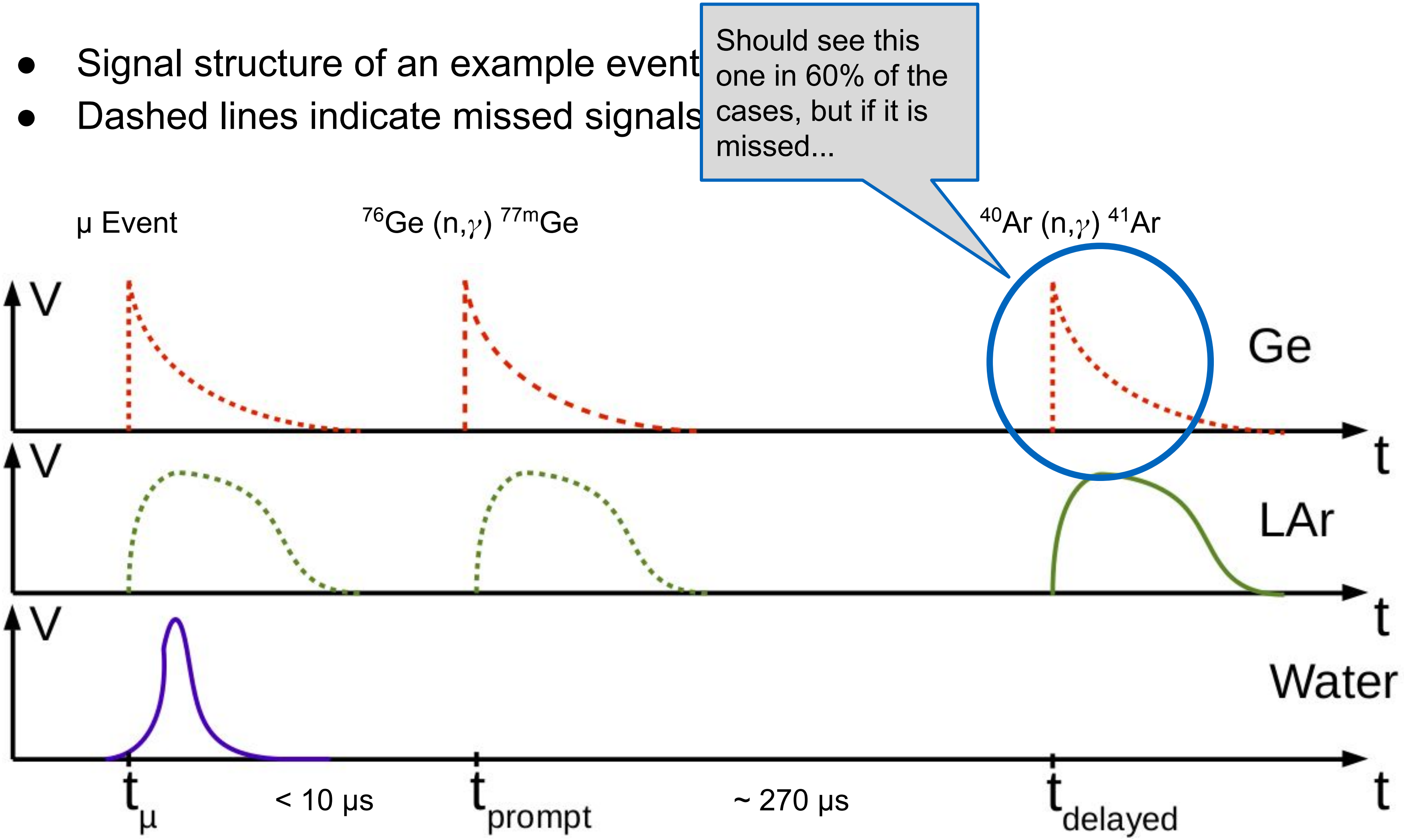

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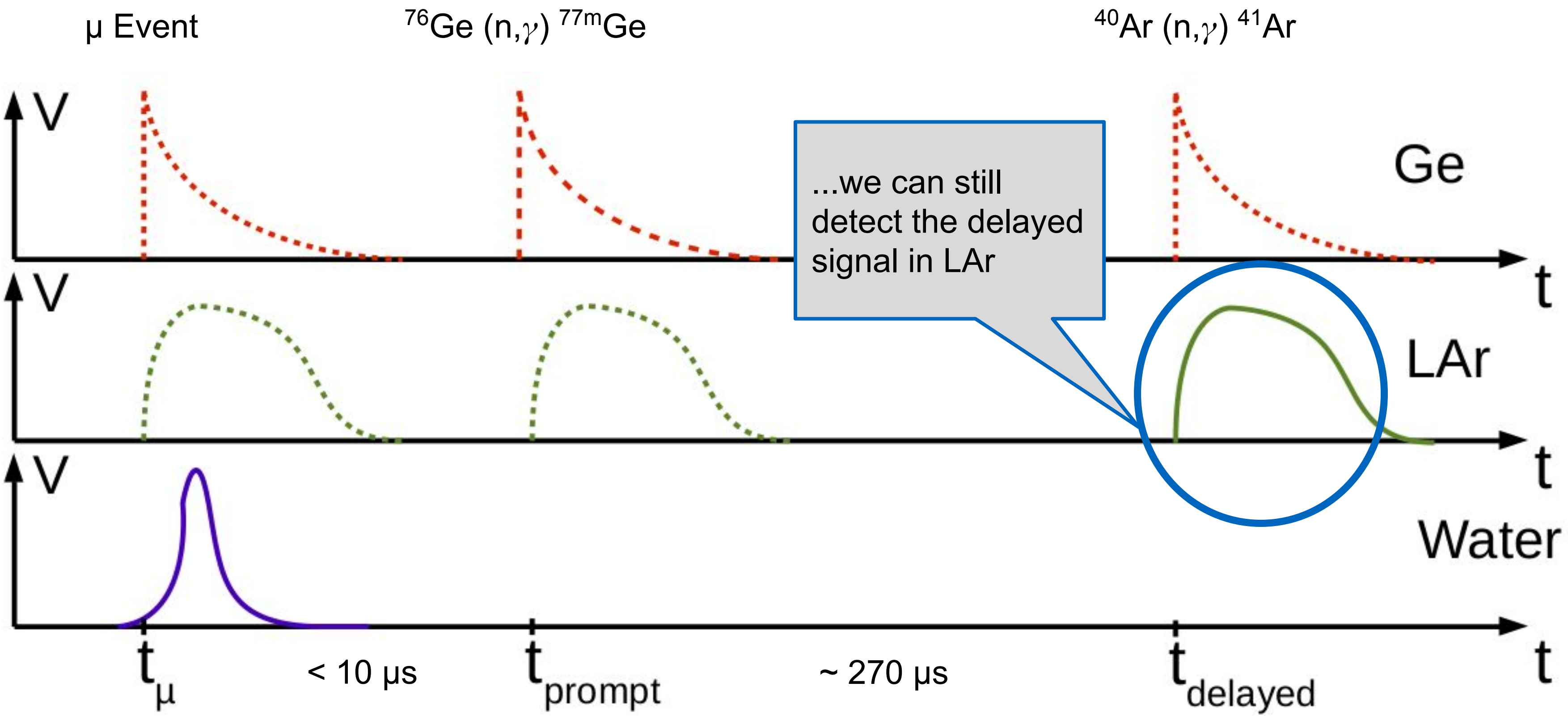
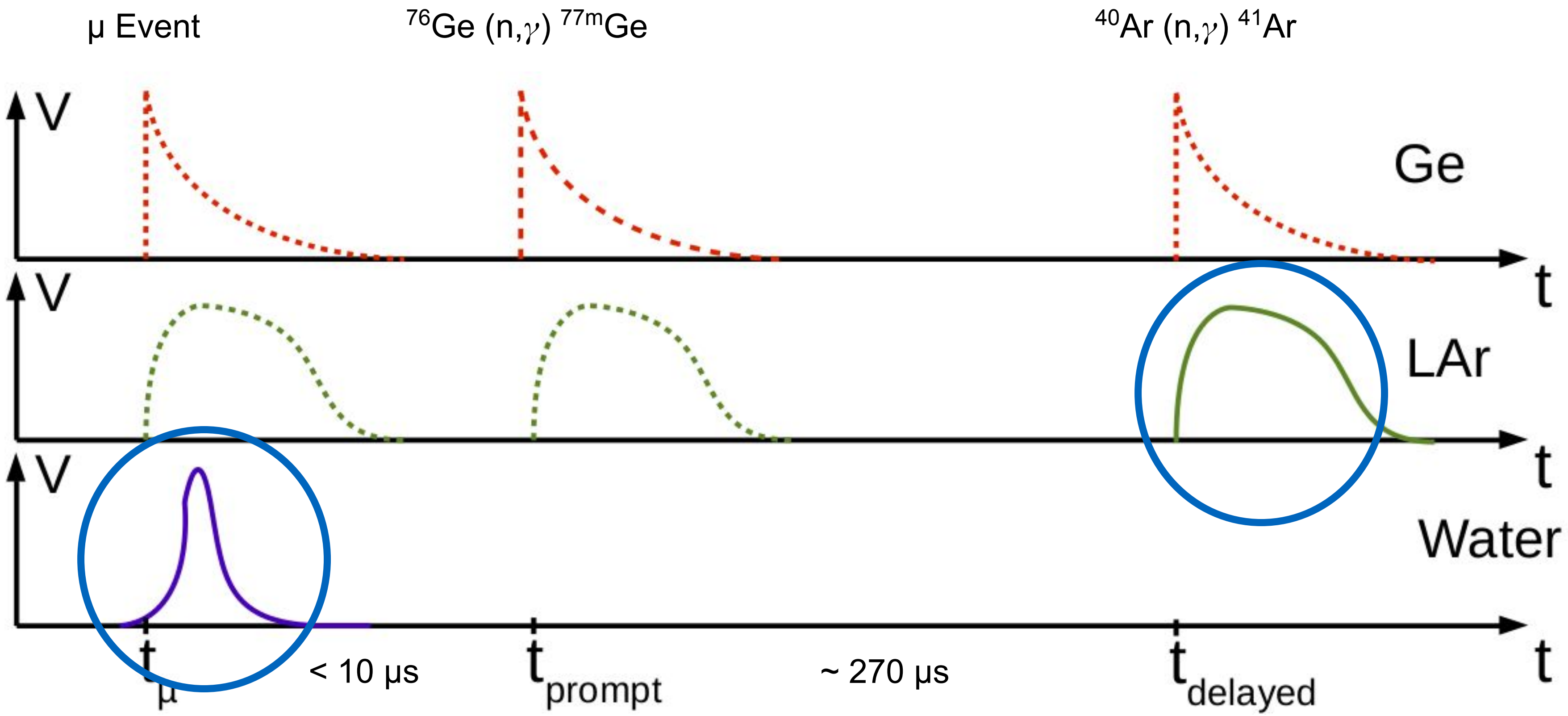


Signal structure of ^{77m}Ge production events

- Possible to tag ^{77m}Ge production by muon veto and delayed LAr signals only
- Delayed signals can reduce dead time compared to prompt signals



Acquisition of ^{77m}Ge production events

- Acquisition of muon veto signals needed (should not be too difficult, 35 mHz rate)
- Germanium traces are already read out in physics runs → no need to implement a new trigger scheme
- Read out of LAr signals simultaneous with Ge signals: already implemented by prompt background suppression
- Read out LAr-only signals is difficult:
  - Trigger rate of ~1 kHz in LAr due to ^{39}Ar
  - Utilize signal topology in order to reduce data rate:
    Readout LAr in a time window after muon signal