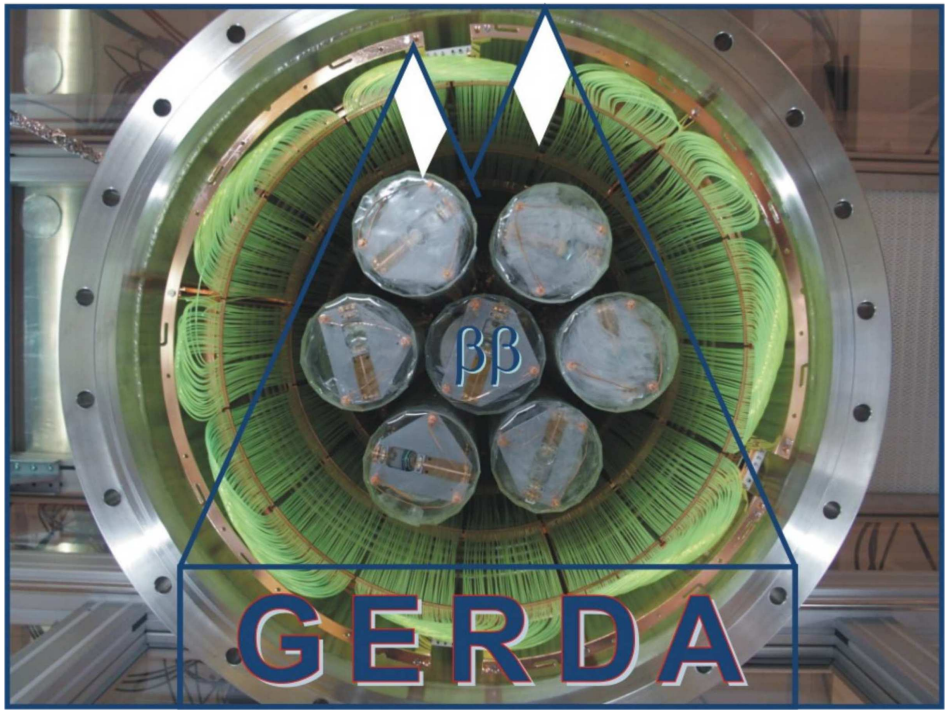
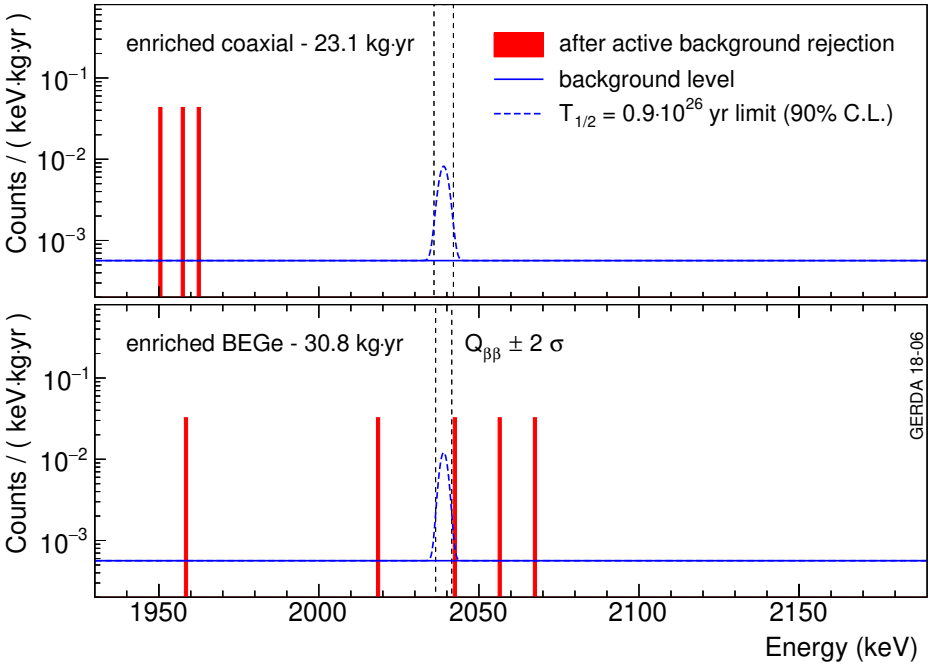
Probing Majorana neutrinos via double-β decay with GERDA

11 July 2019

R. Hiller for the GERDA collaboration



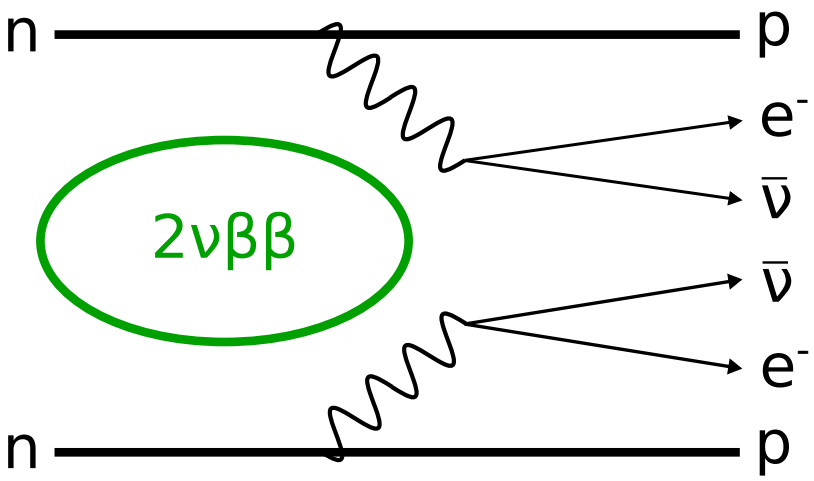


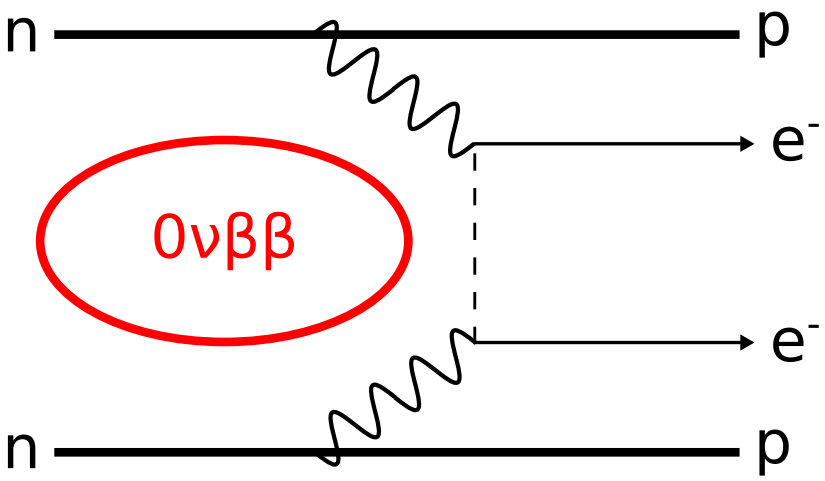
Double beta decay

- (Z,N)→(Z+2,N) + 2e$^-$ + $2\bar{\nu}_e$
- SM, second order weak process
- × β-decay, ✓ $\beta\beta$-decay
- ^{76}Ge $1.926 \pm 0.095 \times 10^{21}$ yr

Eur.Phys. J C 75 (2015) 516

- (Z,N)→(Z+2,N) + 2e$^-$
- Hypothetical, $\Delta L = 2$
- Dirac vs. Majorana fermion
- Potentially sensitive to other ν properties

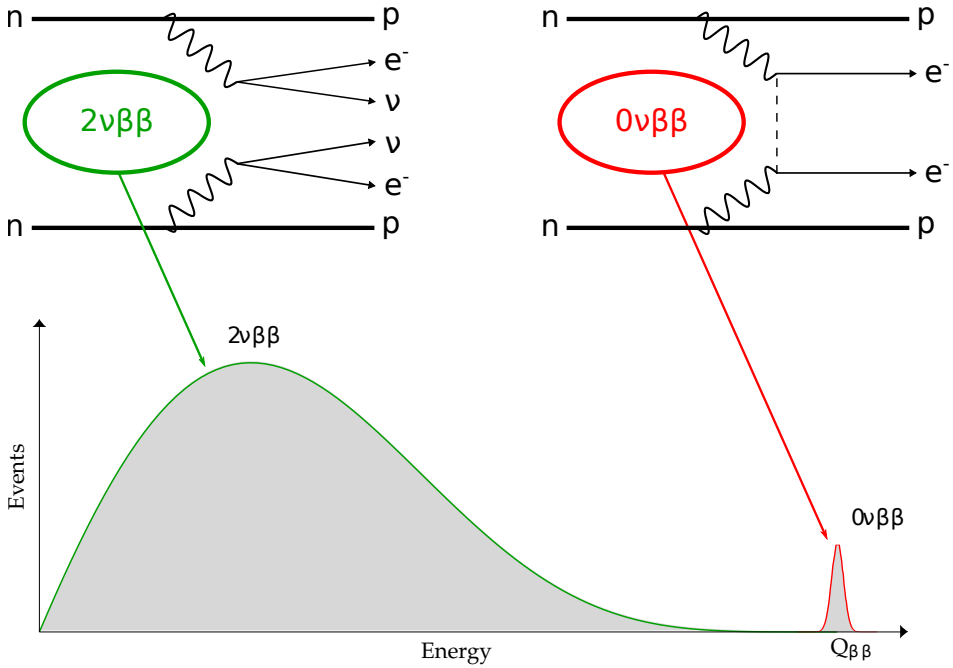




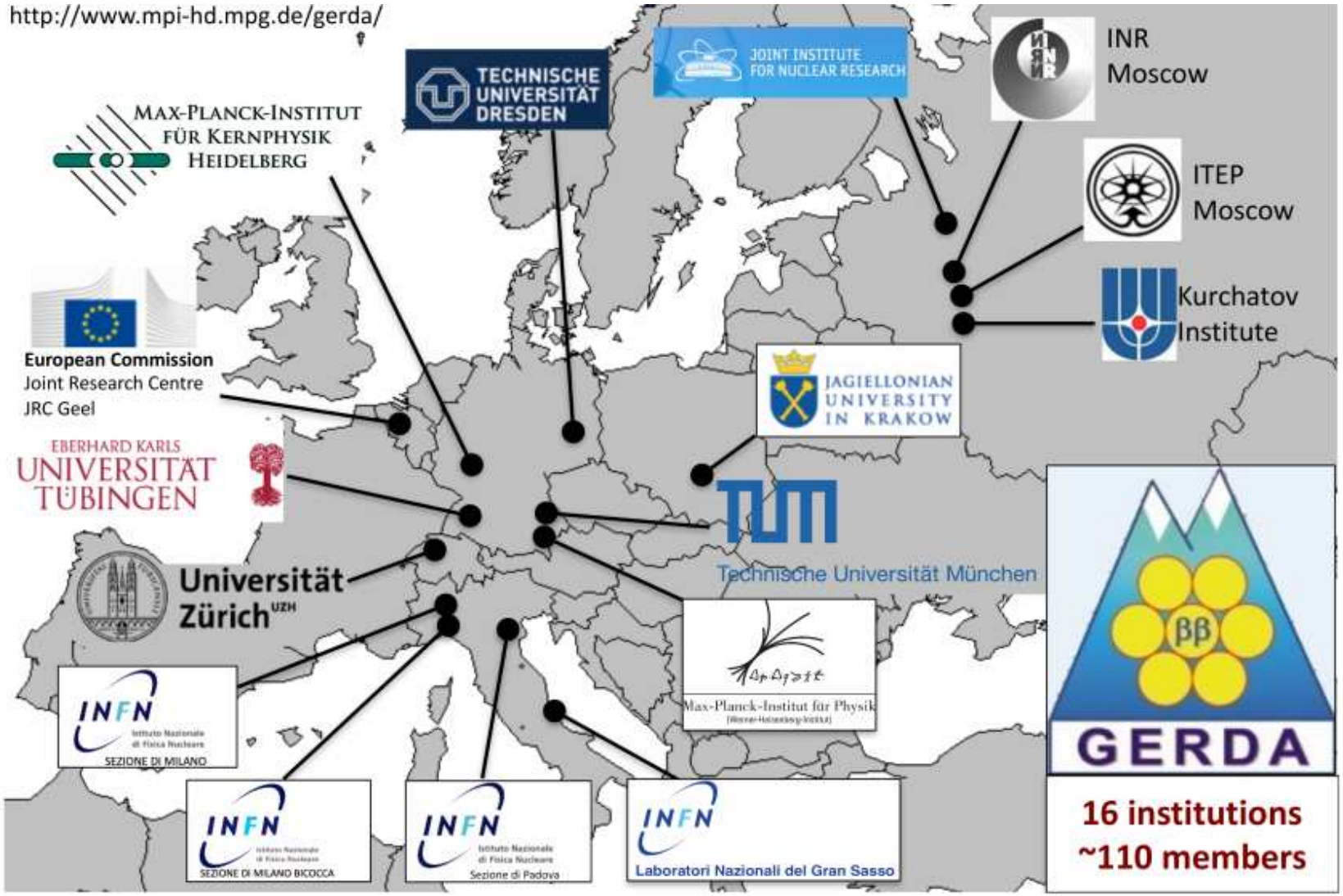
Detection of $0\nu\beta\beta$

- Peak signature at $Q_{\beta\beta}$ in e^--spectrum
- $\mathcal{O}(10)$ experimentally relevant isotopes
- No clear favorite from nuclear physics + phase space
- Sensitivity$\sim\sqrt{\frac{\mathcal{E}}{BI\cdot\Delta E}}$; $\mathcal{E}$=exposure, BI=background index, ΔE=energy resolution
- ^{76}Ge: detector tech. (purity, efficiency, enrichment), energy resolution

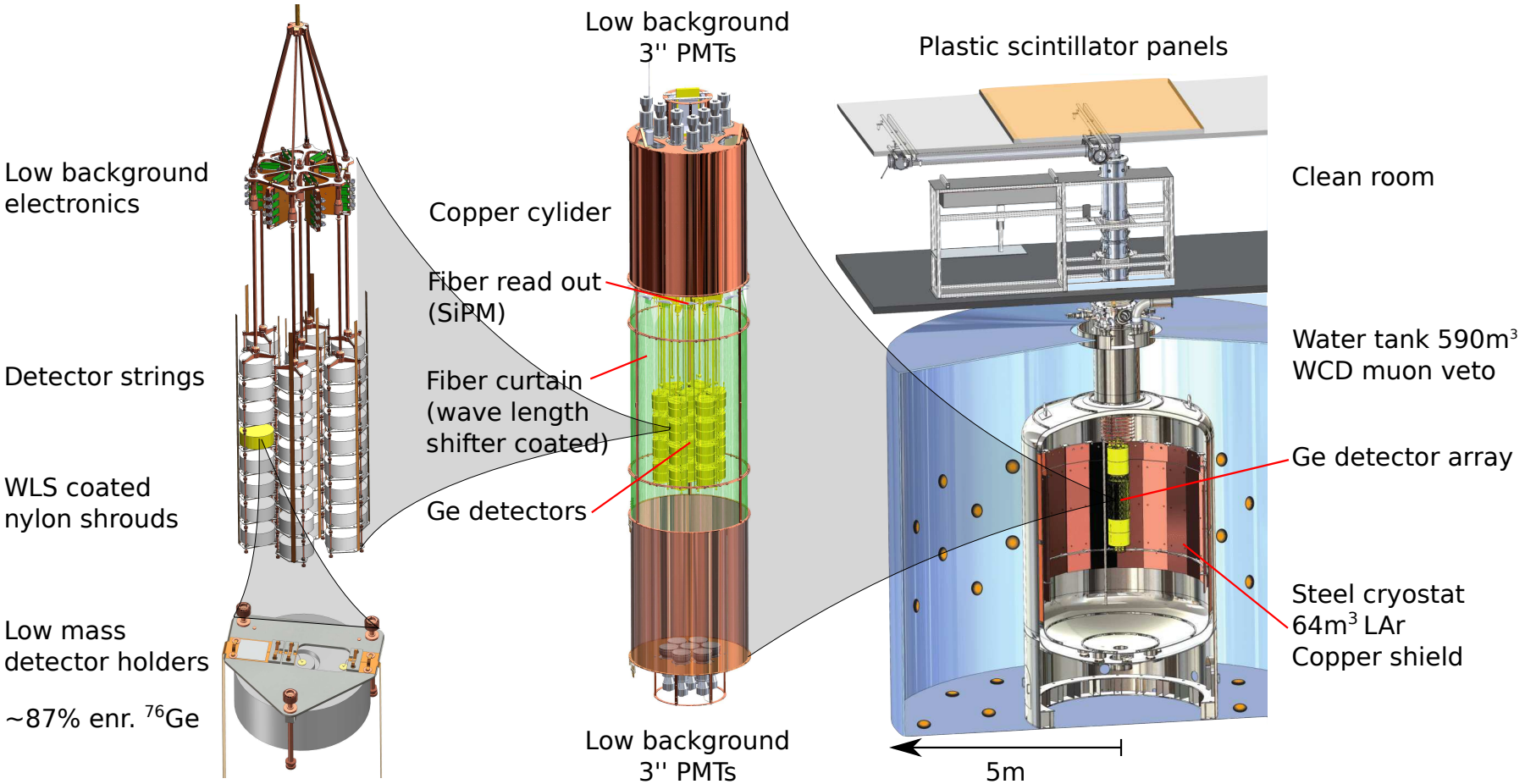
Isotope	Abundance	$Q_{\beta\beta}$ (keV)
^{48}Ca	0.2%	4263
^{76}Ge	7.6%	2039
^{82}Se	9.2%	2998
^{96}Zr	2.8%	3348
^{100}Mo	9.6%	3035
^{116}Cd	7.6%	2813
^{130}Te	34.1%	2527
^{136}Xe	8.9%	2459
^{150}Nd	5.6%	3371



The GERDA collaboration

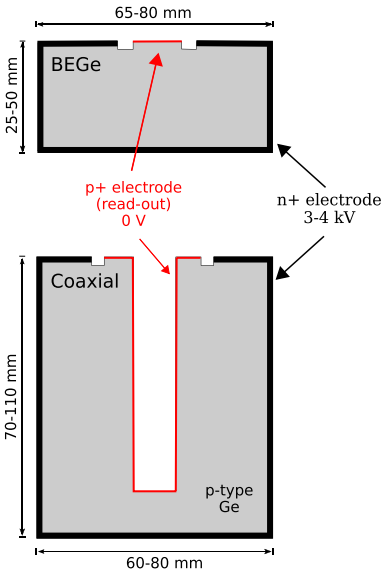


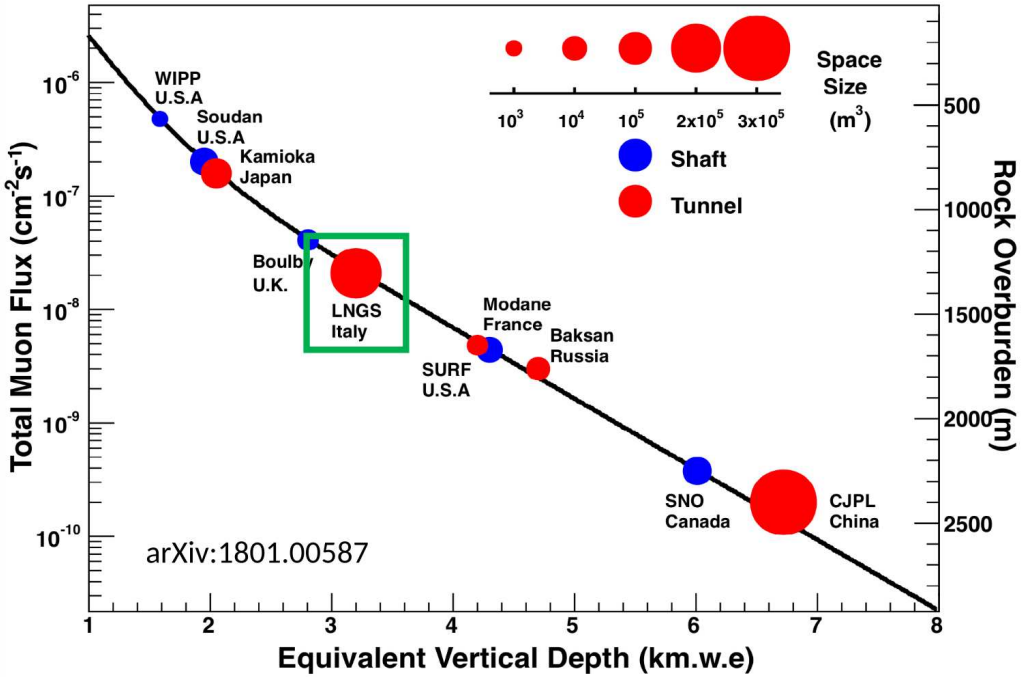
GERmanium Detector Array



The GERDA experiment (until 2018)

- LNGS, Italy, 3500 m.w.e, Muon flux 1 per m^2 h
- Coaxial + BEGe detectors (FWHM 3.6(1)/3.0(1) keV)
- 36 kg Ge, enriched in ^{76}Ge to 88% ($Q_{\beta\beta}$ =2039 keV)
- $\sim 10^{-3} \frac{\text{cts}}{\text{keV kg yr}}$ + 100 kg yr $\rightarrow$sensitivity$\sim 10^{26}$ yr
- Demonstrate LAr concept

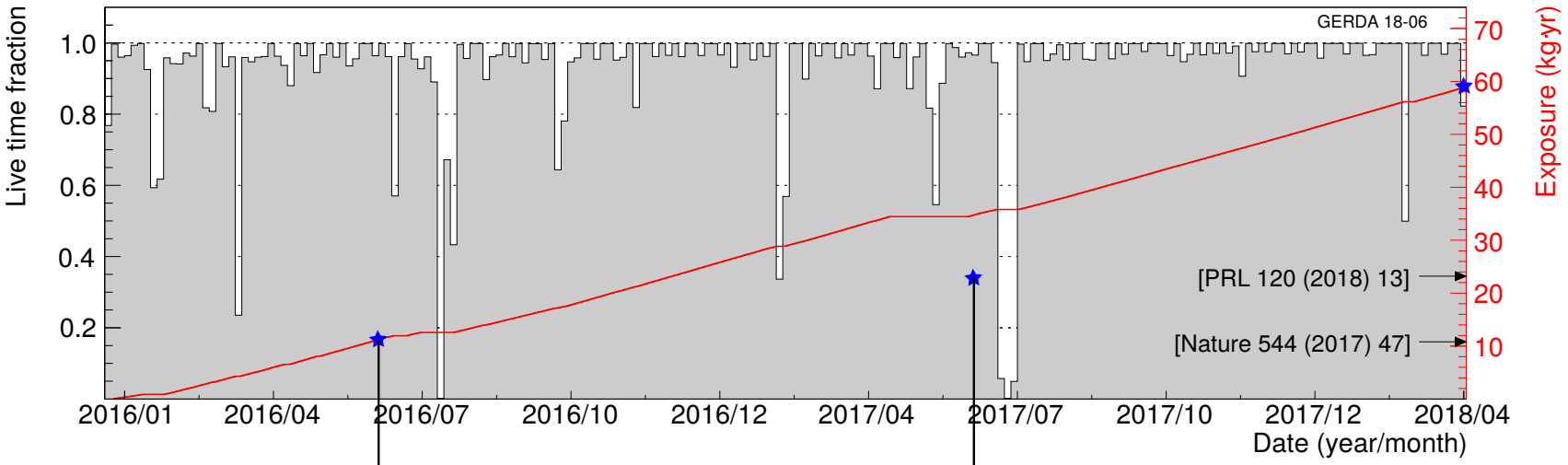




Data taking

Phase II a-c (Dec. 2015-June 2018):

- Blind analysis: Events at 2039±25 keV released after analysis frozen
- Latest release June 2018, total 82.4 kg yr
- 35.7 kg freshly released (Phase IIc)
  +23.2 kg yr (Phase II a+b) + 23.5 kg yr Phase I (2011-2013)



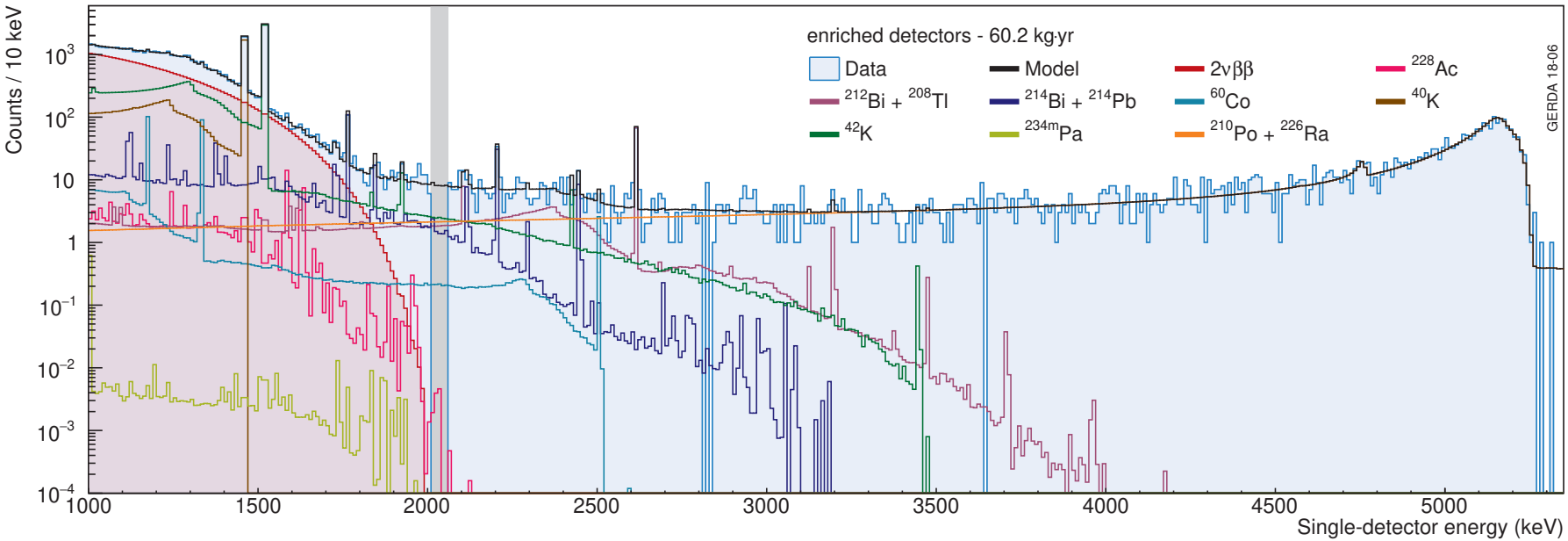
June 2016
10.8 kg yr
Nature 554, 47

June 2017
23.2 kg yr
PRL 120, 132503

June 2018
58.9 kg yr

Background model

- Sources simulated with GEANT4, fit to background data
- Input from screening measurements (via priors)
- Dominating backgrounds at $Q_{\beta\beta}$:
  - degraded α
  - β from ^{42}K
  - γ from U/Th chains

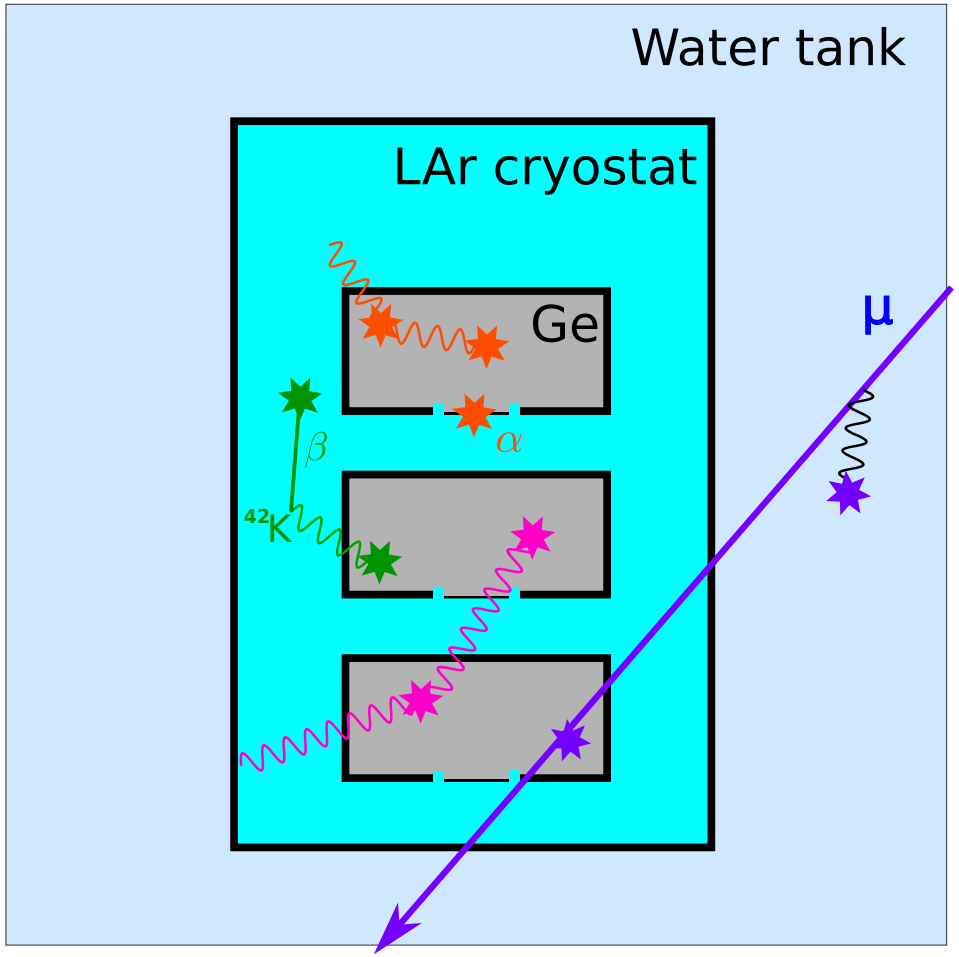


Background reduction

Signal signature = a point-like (⌀ ∼mm) E-deposition in single detector

Pulse shape discrimination vs. multi-site and surface events

LAr scintillation light from external sources

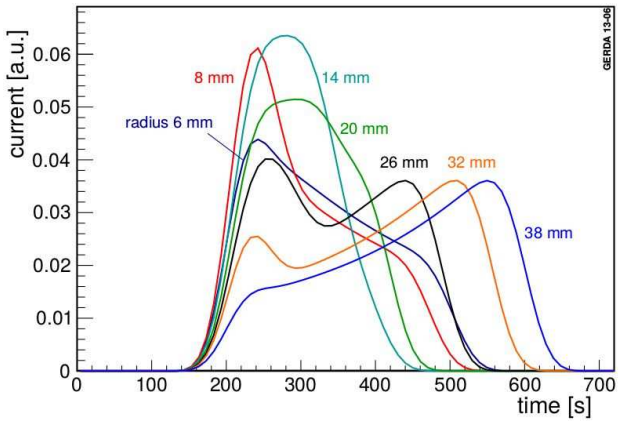


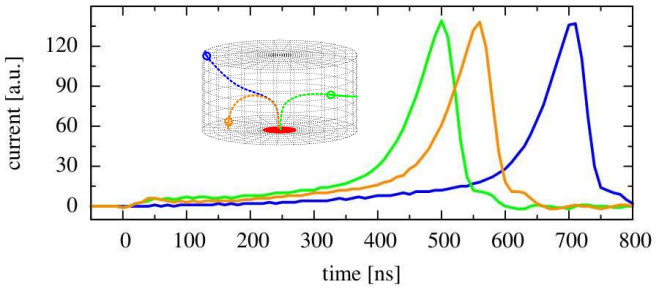
Muon veto via Cherenkov radiation

Detector anti-coincidence

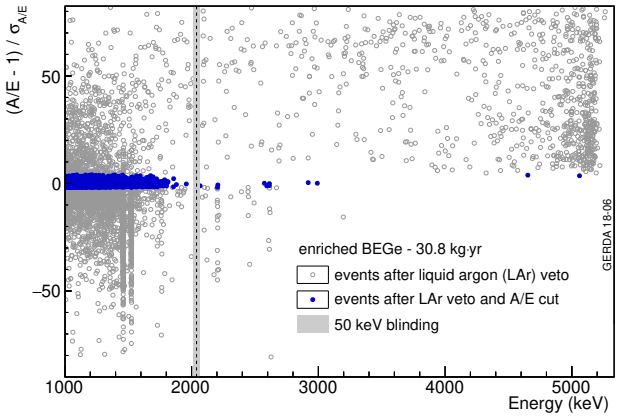
Pulse shape discrimination

- Charge drift time → pulse shape
- Discrimination SSE/MSE, surface:
  - Amplitude/Energy for BEGe (IC)
  - Multivar. analysis (ANN) for coax. MSE
  - Risetime for coaxial alpha

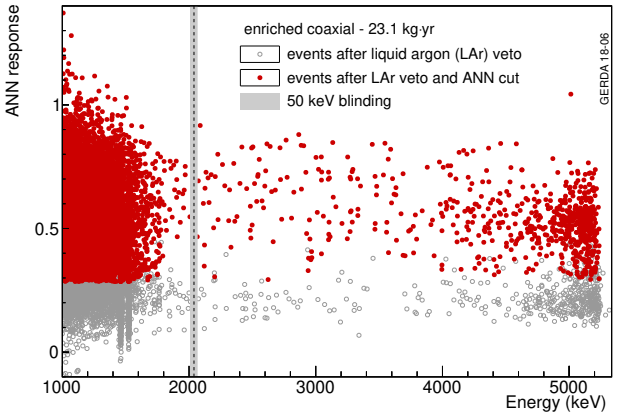




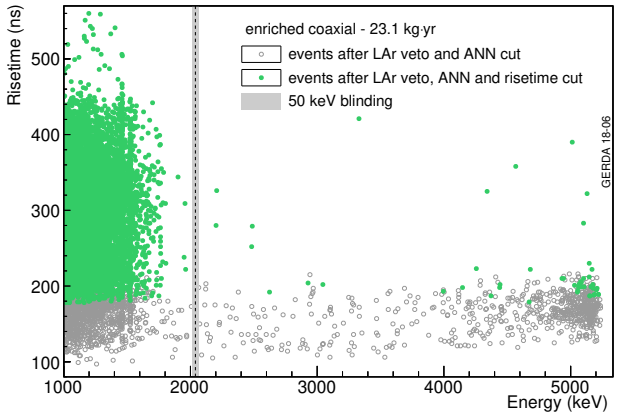
A/E



ANN



Risetime

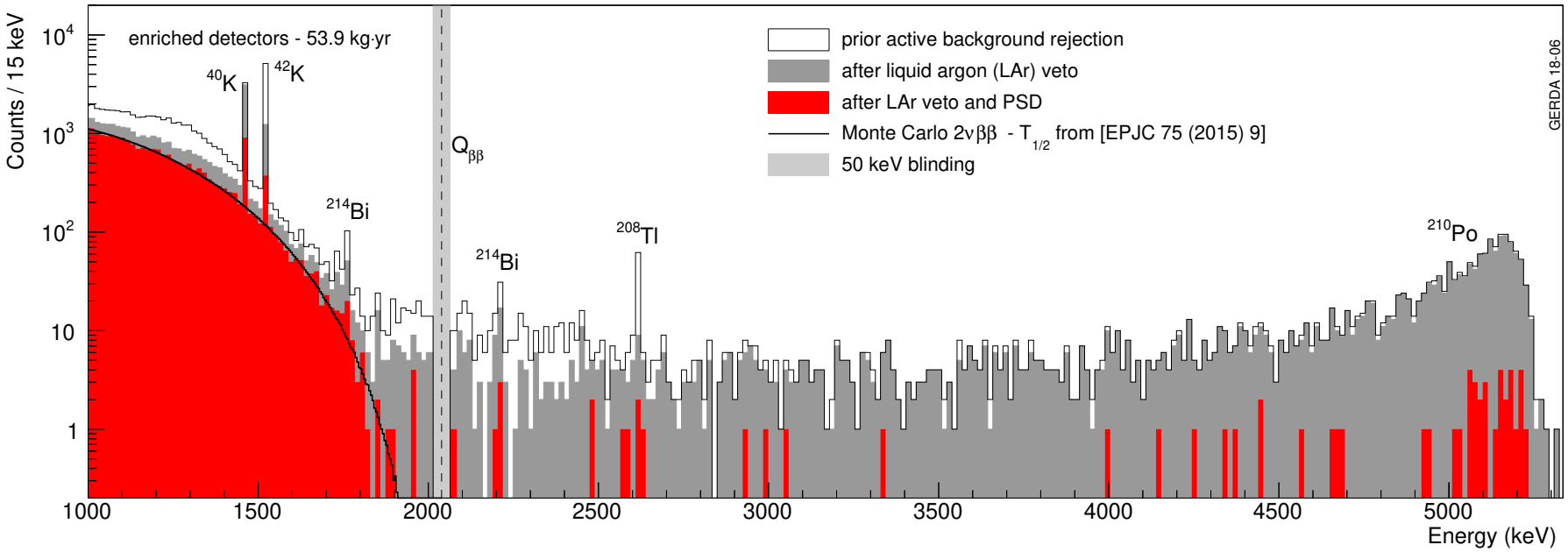


Energy spectrum after cuts

- After LAr veto and PSD cuts background rate in ROI (1930 keV-2130 keV)

$$0.6 \cdot 10^{-3}\,\text{cts}/(\text{keV kg yr})$$

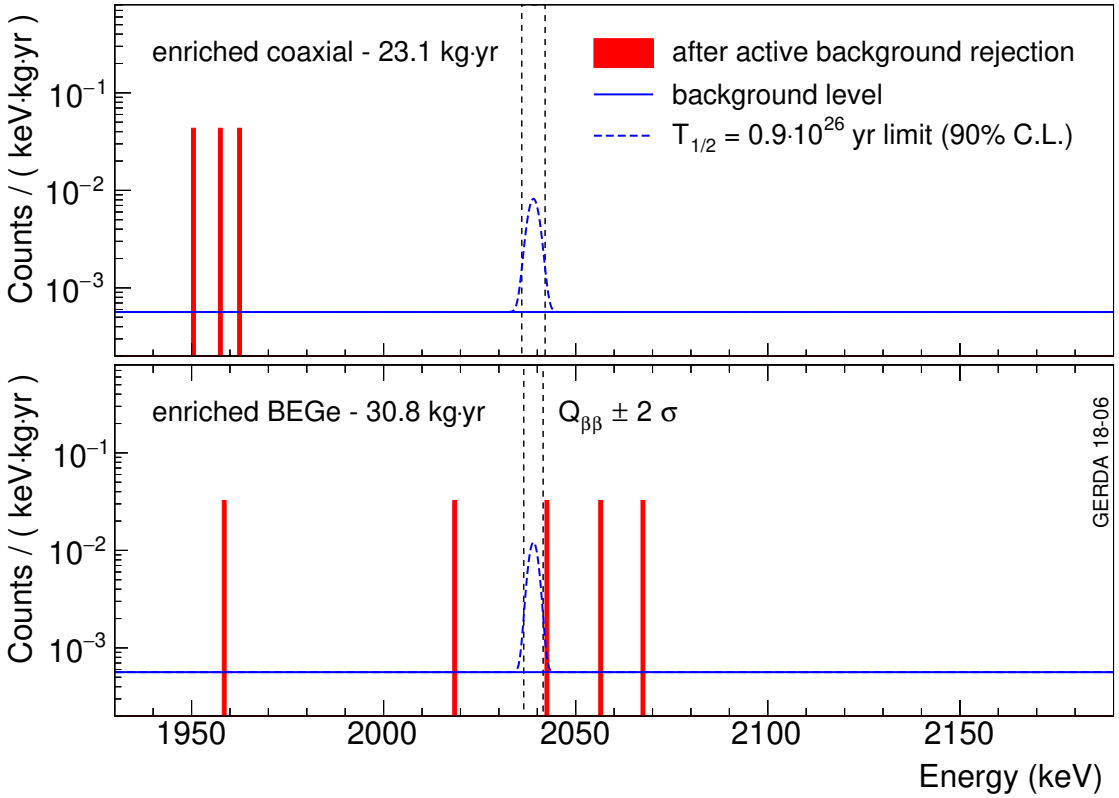
- ∼95% background rejection at ∼86/70% efficiency BEGe/Coax (only LAr veto, PSD)



Statistical analysis in the ROI

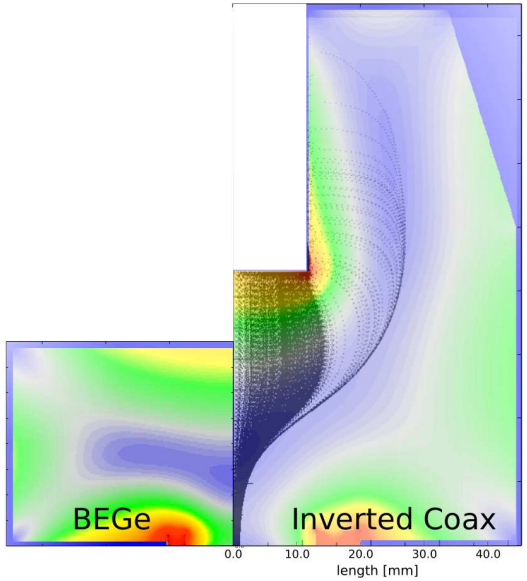
Combined unbinned maximum likelihood fit (7 datasets PI + PII)
(Methods in Agostini et al., Nature 544, 47-52, 2017)

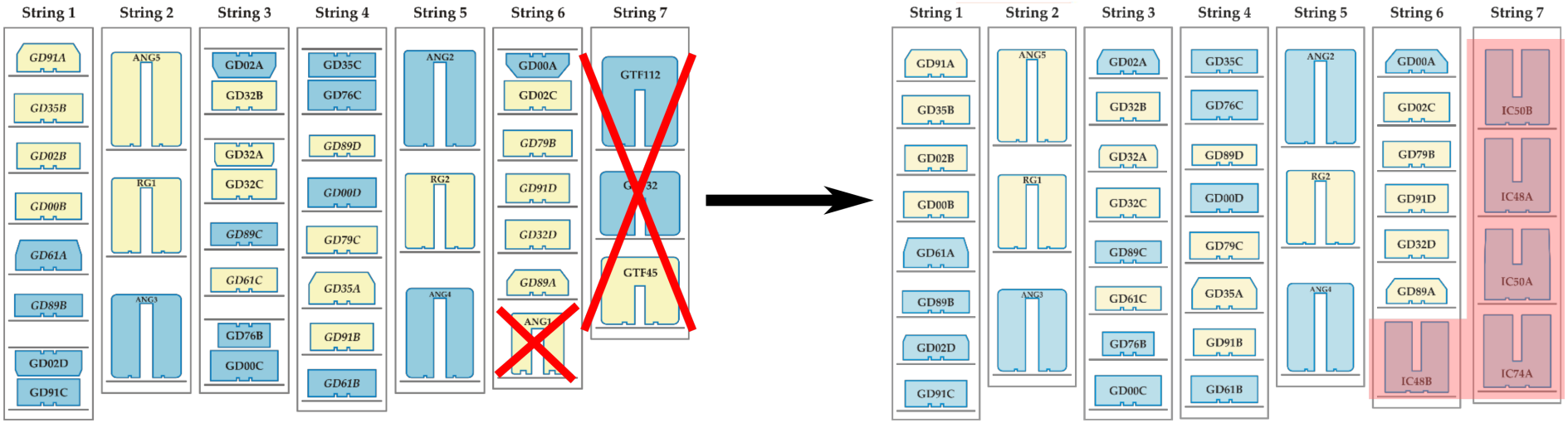
- Data up to mid 2018
- 1st event in ROI
  ($> 2\sigma$ away from $Q_{\beta\beta}$)
- Best fit for no signal
- Half-life lower limit
  $0.9 \cdot 10^{26}$ yr (90% CL)
- Median sensitivity
  $1.1 \cdot 10^{26}$ yr



GERDA upgrade-I

- Following data release ∼2 month interruption
- Replace natural Ge detectors with 5 new Inverted Coaxial type (∼9 kg)



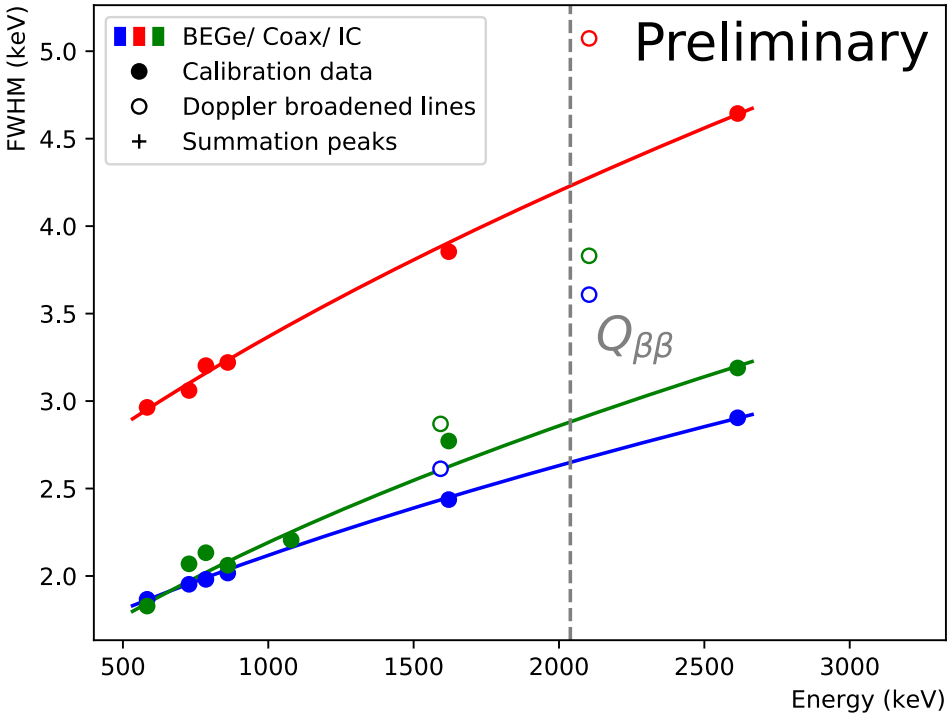


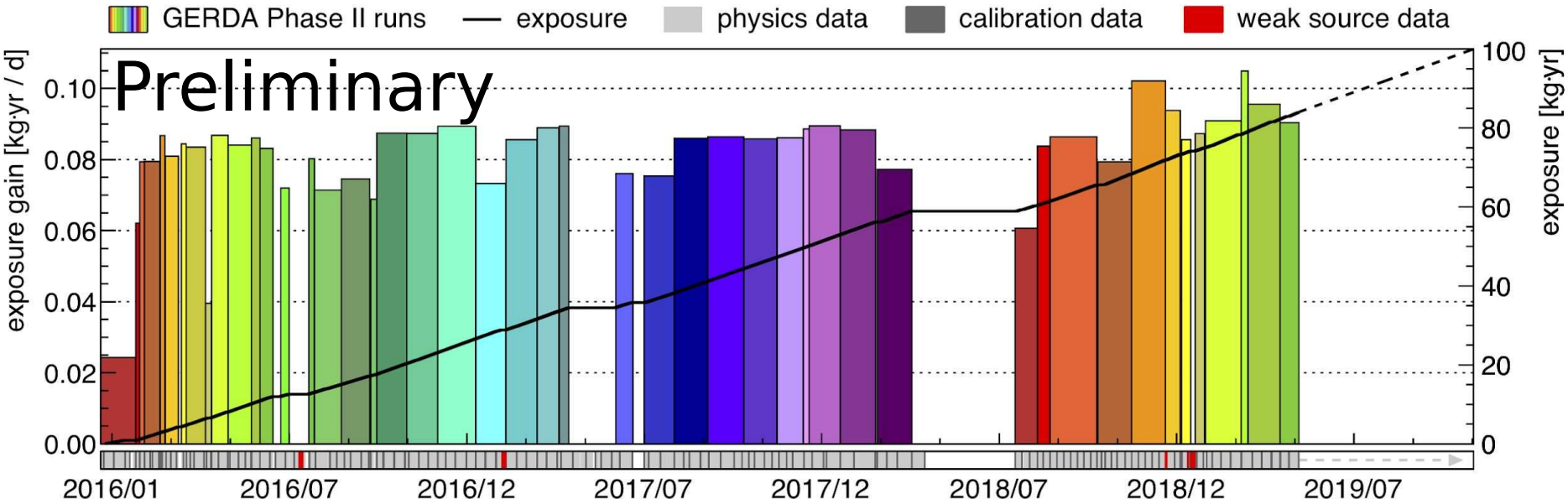
GERDA upgrade-II

- Install denser fiber curtain and middle string curtain
- Repair electronics and maintain a few detectors
- Replace cables to reduce radioactivity and crosstalk

GERDA post upgrade

- GERDA back online with additional mass
- Acquired already ∼25 kg yr
- Approaching 100 kg yr (∼Nov.)
- IC detectors perform well (FWHM∼2.8 keV)

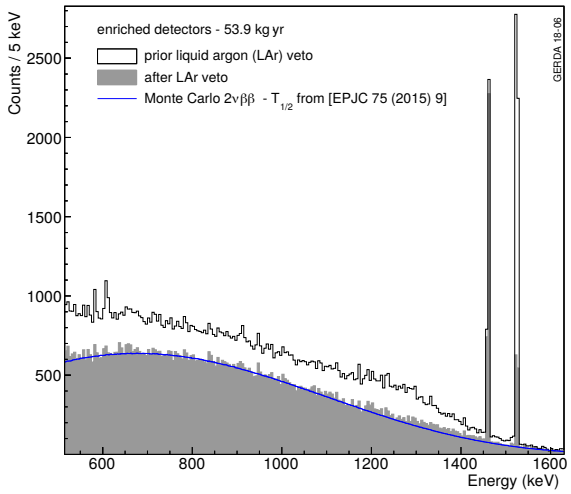




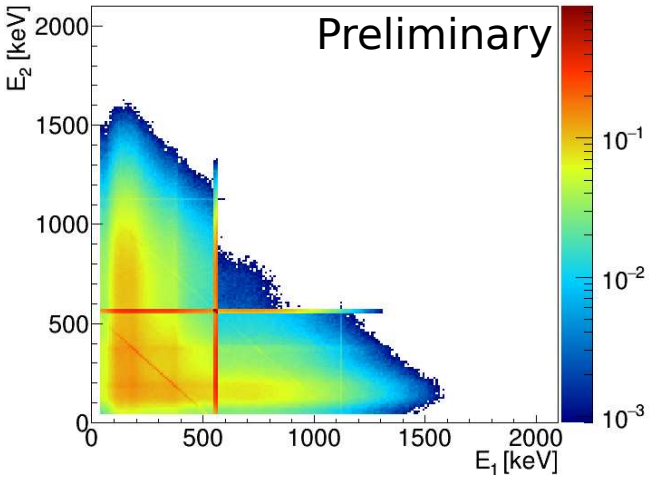
GERDA plans

- Last unblinding ($0\nu\beta\beta$) planned for mid 2020
- Analysis of $2\nu\beta\beta$ spectrum and distortions (e.g. Majorons)
- $2\nu\beta\beta$ to excited states (via coincidences)
- Search for keV dark matter

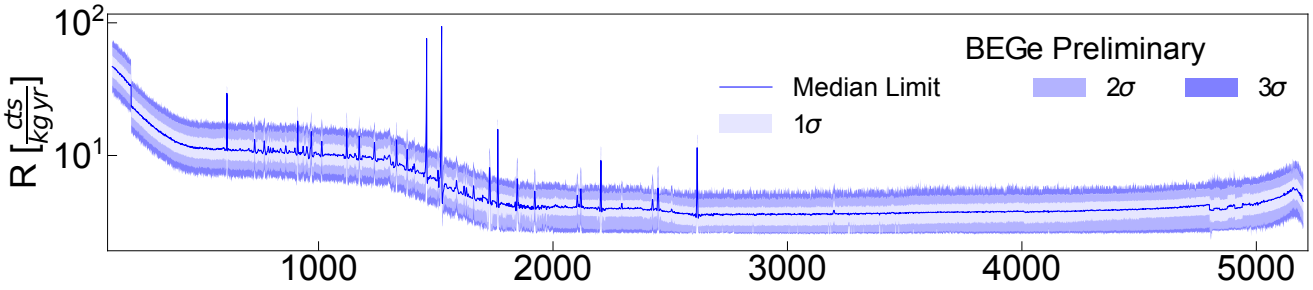
$2\nu\beta\beta$ spectrum



Coincidence spectrum



Peak rate sensitivity



Conclusion

- GERDA surpassed sensitivity of 10^{26} yr
- Effectively background-free + exposure of 82.4 kg yr
- After upgrade mass at 44kg, approaching target 100 kg yr
- Data taking planned until end of 2019, afterwards continue with LEGEND-200 at LNGS