

FINAL RESULTS OF GERDA ON THE SEARCH FOR NEUTRINOLESS DOUBLE- β DECAY

L. Pertoldi <luigi.pertoldi@tum.de>

PANIC 2021 • 8 Sep 2021

TU München, INFN Padova



Quite a peculiar and interesting process¹

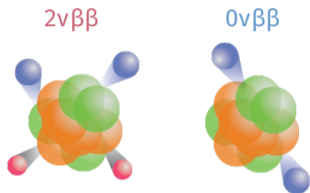
- $0\nu\beta\beta$ observation \Rightarrow Majorana neutrino and Lepton Number Violation
- Lepton number \longleftrightarrow Barion number \mapsto new physics, baryogenesis?

Light neutrino mass mechanism

The (Majorana) neutrino that mediates $0\nu\beta\beta$ is the one that oscillates and the Standard Model is an effective theory (*seesaw mechanism*)

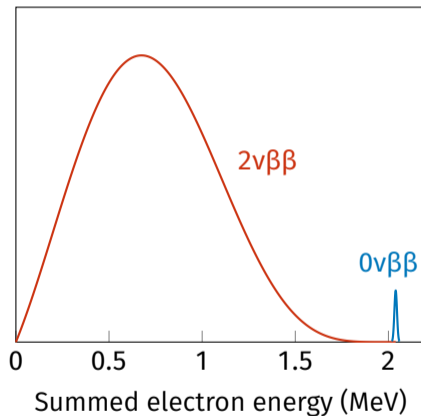
$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu} |M^{0\nu}|^2 \langle m_{\beta\beta} \rangle^2$$

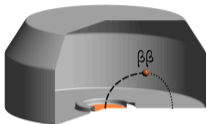
¹100+ papers per year with “ $0\nu\beta\beta$ ” in the title [[INSPIRE-HEP statistics](#)]



All experiments measure the **total energy of the two emitted electrons**

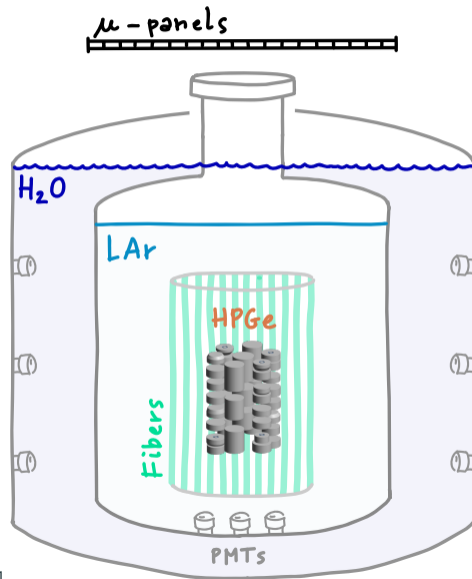
↳ *necessary and sufficient* for discovery



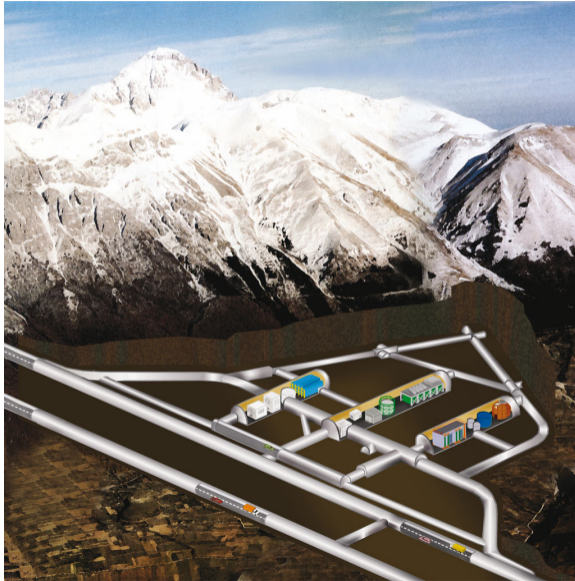


High-Purity Germanium detectors enriched in ${}^{76}\text{Ge}$

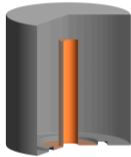
- source = detector \mapsto *high efficiency*
- pure \mapsto *low intrinsic background*
- Ge crystal \mapsto *outstanding energy resolution*
- solid-state TPC \mapsto *topological discrimination*



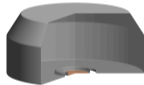
GERMANIUM DETECTOR ARRAY AT LNGS



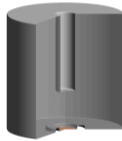
- 35.6 kg (later 44.2 kg) of HPGe REF [EPJC 79 \(2019\) 11, 978](#) REF [EPJC 81 \(2021\) 505](#)



(semi-)Coaxial

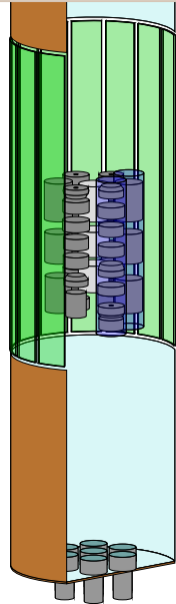


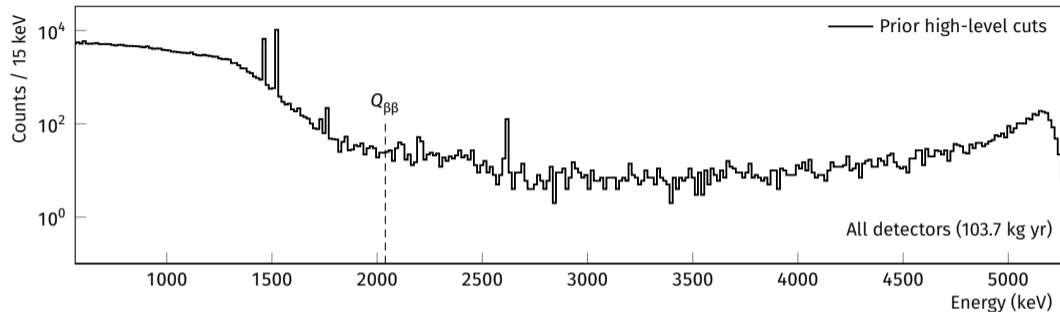
BEGe



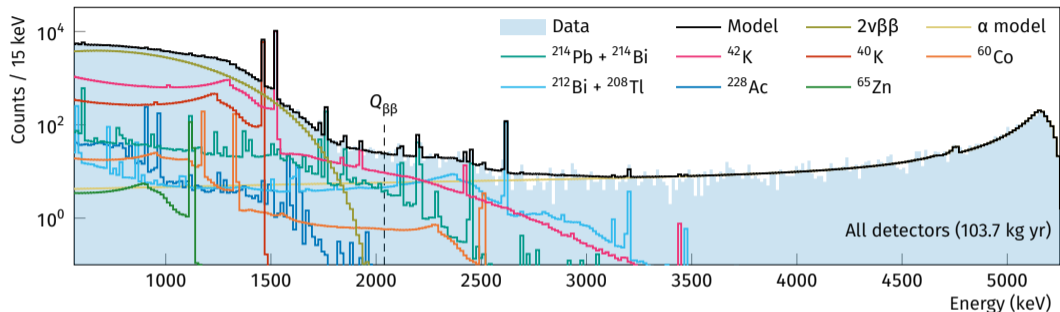
ICPC

- Hybrid **LAr light collection system**: WLS fibers / SiPMs / PMTs
- **μ -veto**: water Cherenkov, scintillating panels REF [EPJC 76 \(2016\)298](#)
- Ultra **radio-pure** materials, small passive mass, deep underground

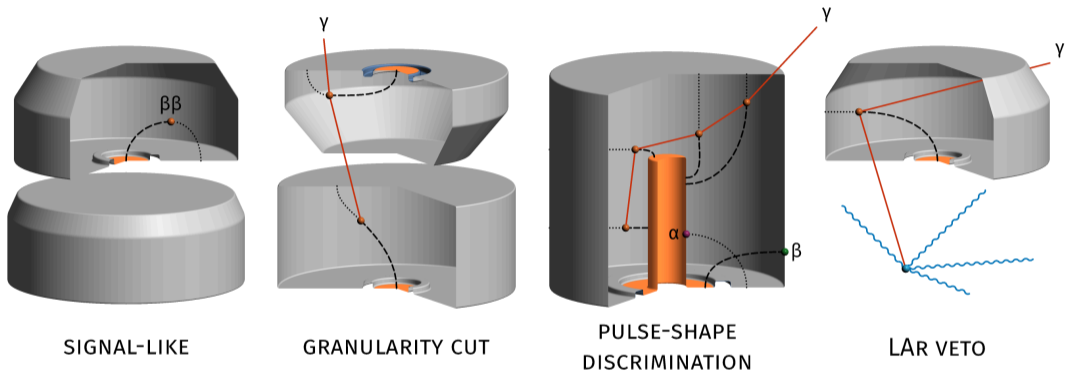




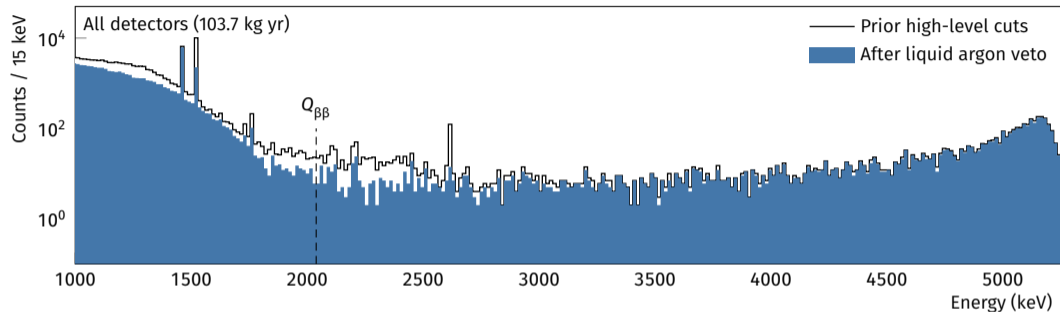
- Data taken from Dec 2015 to Nov 2019 (~90% duty cycle, including upgrade works)
- Energy resolution: ~ 0.1% FWHM at $Q_{\beta\beta}$ [REF Eur. Phys. J. C 81 \(2021\) 8, 682](#)
- 103.7 kg yr of exposure selected for analysis, largest ever collected with ^{76}Ge



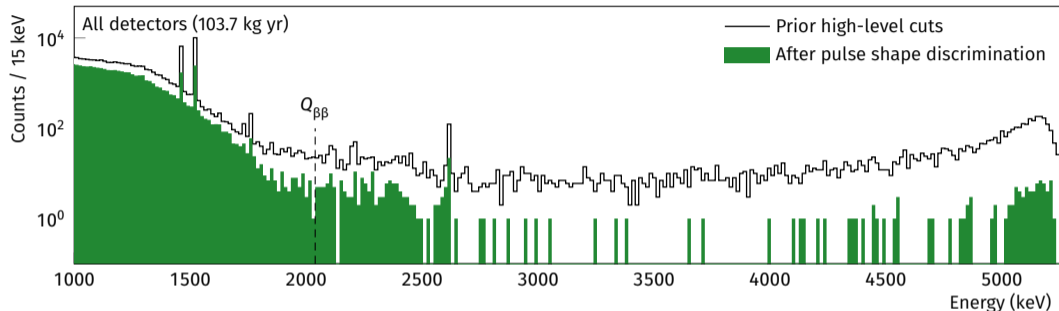
- Bayesian multivariate fit of Monte Carlo predictions (with screening measurements as priors)
- $Q_{\beta\beta}$ dominated by β from ^{42}K (from ^{42}Ar in LAr), α from ^{210}Po , γ from ^{228}Th and ^{238}U chains
- Results are input to several physics analyses and inform future experiments (LEGEND)



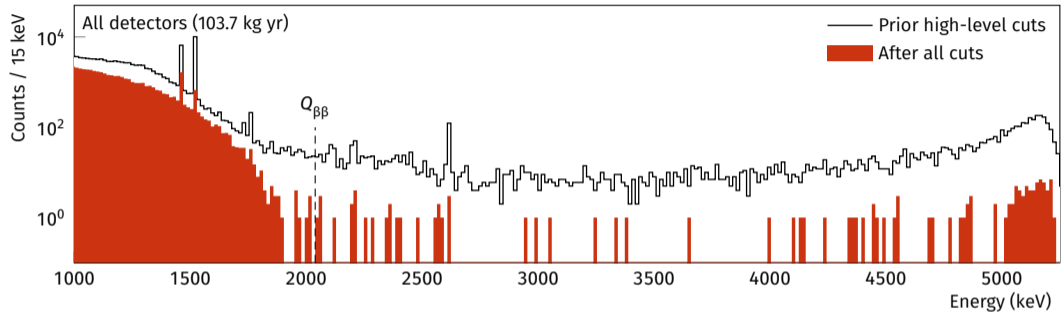
Combined $0\nu\beta\beta$ detection efficiency between 45–65% depending on the detector type



- Anti-coincidence between HPGe trigger and SiPM/PMT data (≥ 0.3 p.e. in a 5 μ s window)
- $0\nu\beta\beta$ signal efficiency > 97% (random coincidences)
- Publication on Monte Carlo modeling [REF](#) in preparation



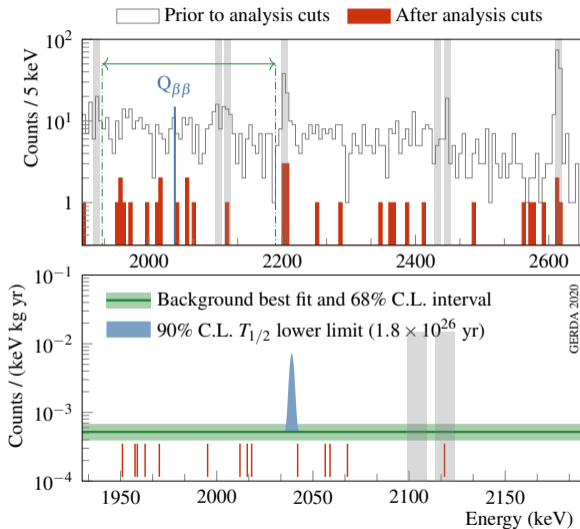
- Point-contact detectors: two-sided **univariate A/E cut** REF JINST 4 (2009) P10007
- Coaxial detectors: **artificial neural network** and **risetime cut** REF EPJC 73 (2013) 10, 2583
- $0\nu\beta\beta$ signal efficiency: 90% (70% for coaxials)

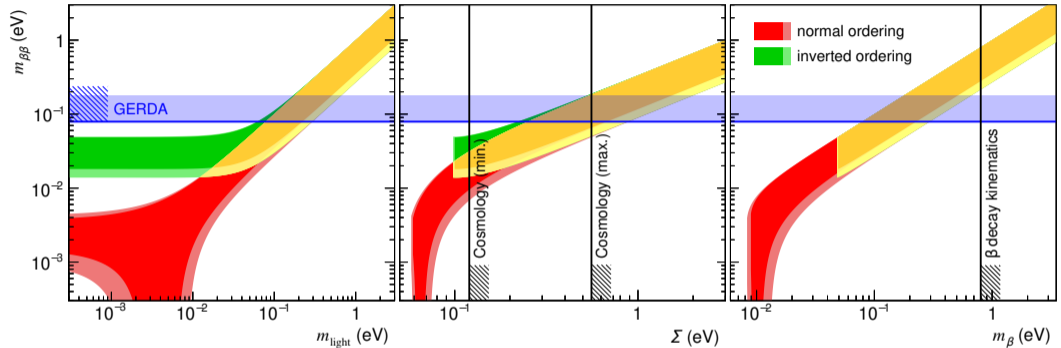


- Extremely low event rate at $Q_{\beta\beta}$ of $\sim 5 \cdot 10^{-4}$ cts / (keV kg yr) \mapsto *quasi-background-free*
- Few events at $Q_{\beta\beta}$ \mapsto *“simple” background-model-free analysis*
- Nearly pure $2\nu\beta\beta$ spectrum

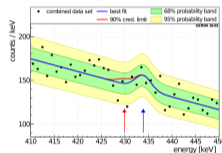
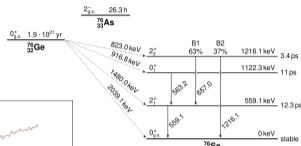
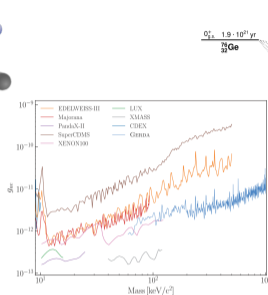
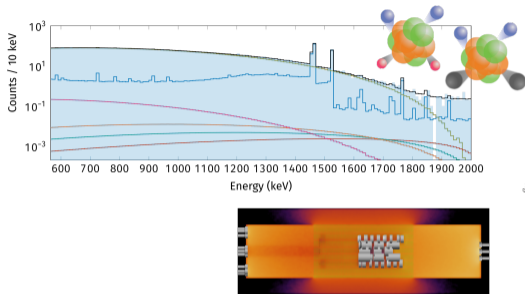
Tracking of parameters in time
 → *advanced statistical analysis*

- $5.2^{+1.6}_{-1.3} \cdot 10^{-4}$ cts / (keV kg yr) at $Q_{\beta\beta}$
- No signal in 127.2 kg yr of exposure
 (includes 23.5 kg yr from Phase I with a background of $\sim 10^{-2}$ cts / (keV kg yr))
- $T_{1/2}^{0\nu} > 1.8 \cdot 10^{26}$ yr (90% C.L. frequentist)
 (equal to median expectation in absence of signal)
- $\langle m_{\beta\beta} \rangle < 79\text{--}180$ meV

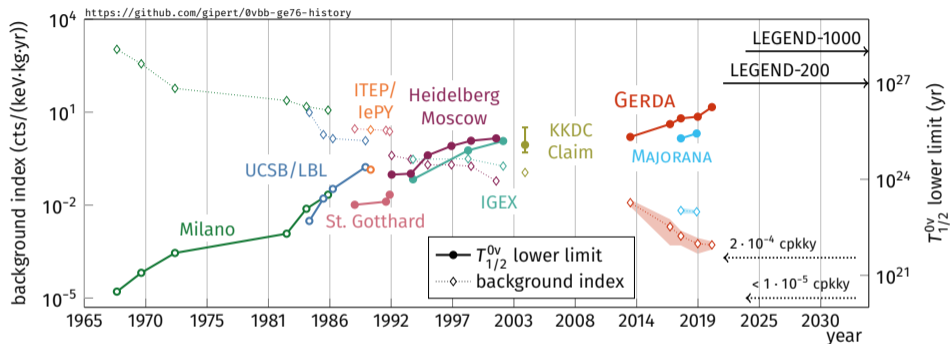




- Getting closer to the inverted ordering region, paving the way to [LEGEND](#)
- Interplay with cosmology (Σ) and direct measurements (m_{β})



- $2\nu\beta\beta$ half-life measurement [REF Eur. Phys. J. C 75 \(2015\) 416](#) [REF new in preparation](#)
- New-physics searches (Majorons, Lorentz violation...) [REF Eur. Phys. J. C 75 \(2015\) 416](#) [REF new in preparation](#)
- $\beta\beta$ -decay excited states [REF J. Phys. G: Nucl. Part. Phys. 42 \(2015\) 115201](#) [REF new in preparation](#)
- Dark matter (WIMP) searches [REF Phys. Rev. Lett. 125, 252502 \(2020\)](#)
- ^{36}Ar double electron capture [REF Eur. Phys. J. C 76 \(2016\) 652](#) [REF new in preparation](#)
- Monte Carlo modeling of the LAr detector [REF in preparation](#)



- Impressive technological progress and scientific production
- A new exciting era begins now with **LEGEND**

“...an era in which a discovery could come at any time!”

LEGEND-200

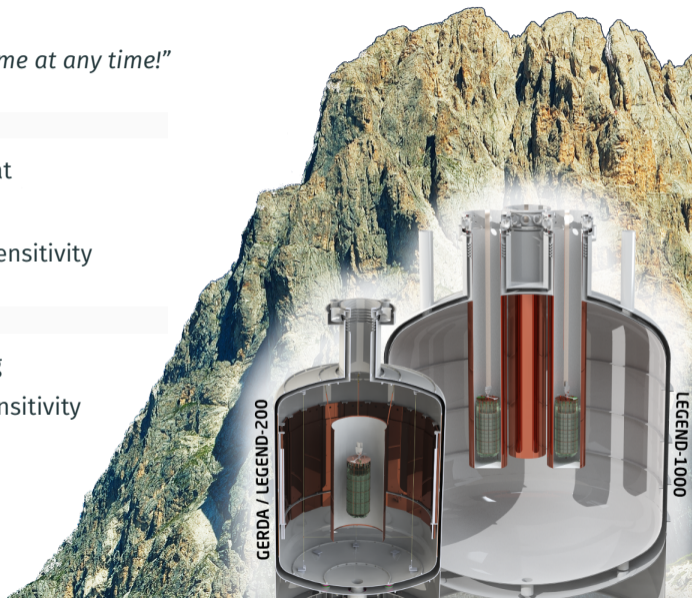
- 200 kg of ^{enr}Ge ($\times 5$ yr), in GERDA cryostat
- Funded, under construction
- $2 \cdot 10^{-4}$ cts / (keV kg yr) $\mapsto > 10^{27}$ yr sensitivity

LEGEND-1000 [arXiv 2107.11462](https://arxiv.org/abs/2107.11462)

- 1 ton of ^{enr}Ge ($\times 10$ yr), awaiting funding
- $< 10^{-5}$ cts / (keV kg yr) $\mapsto > 10^{28}$ yr sensitivity
- Cover $\langle m_{\beta\beta} \rangle$ inverted ordering region

LEGEND @ PANIC

W. Pettus (overview), CJ Barton (cosmogenics),
M. Harańczyk (LAR purification)



BACKUP

ENERGY CALIBRATION

