



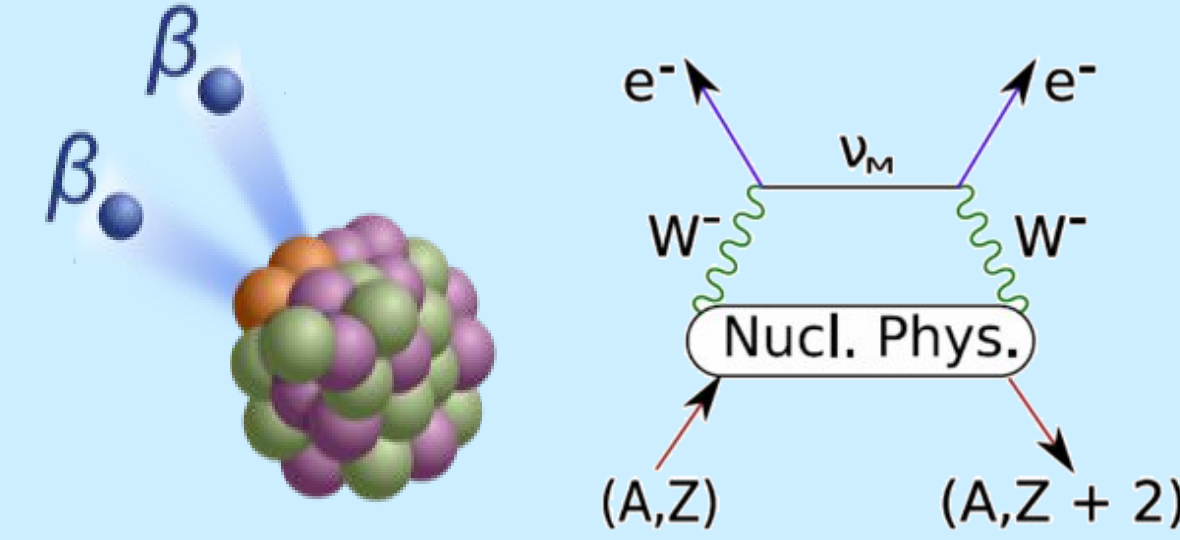
LEGEND

Mission: Develop a phased, ^{76}Ge based double-beta decay experimental program with discovery potential at a half-life beyond 10^{28} years

Neutrinoless $\beta\beta$ -decay ($0\nu\beta\beta$) is a rare nuclear process that transforms two neutrons into two protons, two electrons, and zero neutrinos¹

Never observed before. Observation would:

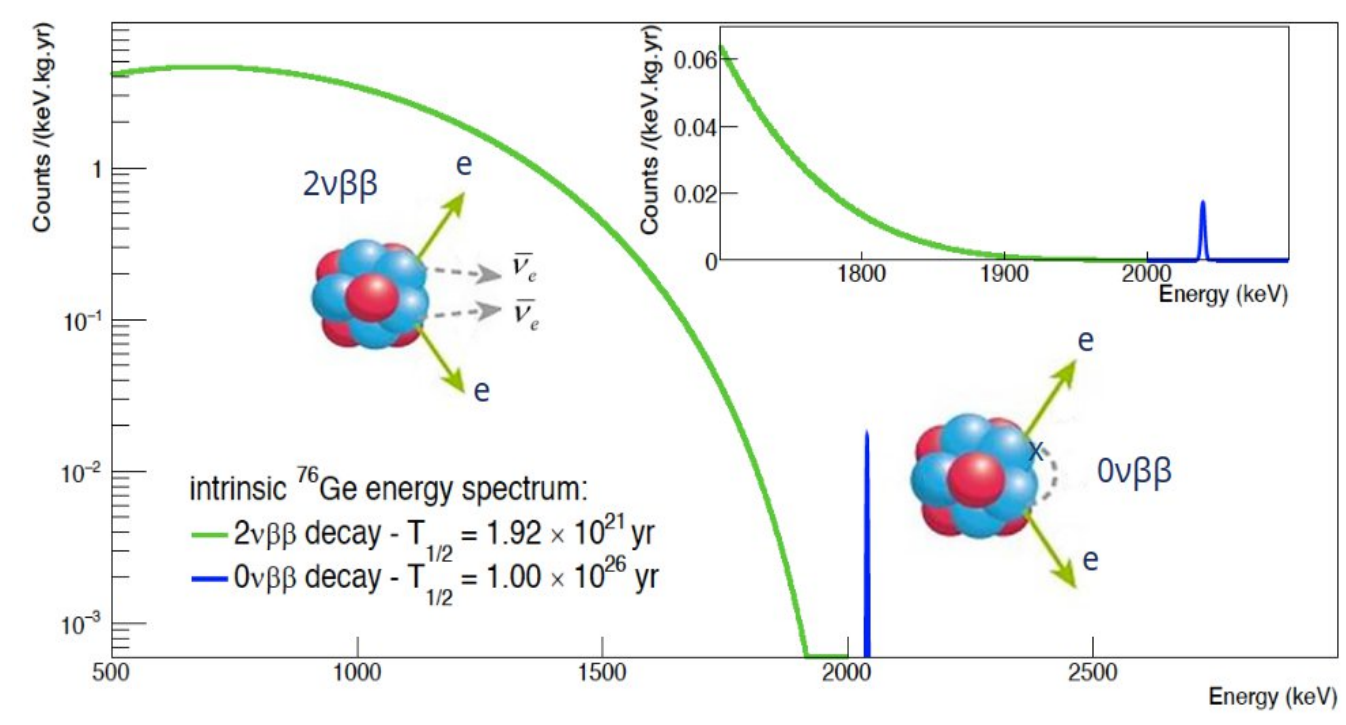
- Prove neutrino is a Majorana fermion (its own anti-particle)
- Show lepton number violation happens in nature (leptogenesis mechanism!)
- Help explain low mass of neutrino (see-saw mechanism)



No neutrinos means all kinetic energy in decay is detected: peaked detection signature!

LEGEND's detection strategy:

- Deploy an array of high purity germanium (HPGe) detectors enriched to >90% in ^{76}Ge to act as source and detector
- Submerge array in liquid argon (LAR) that acts as cryogen and is instrumented to act as a active shield
- Use point contact detectors that have world-leading energy resolution and pulse-shape discrimination (PSD) capabilities
- Deploy at Laboratori Nazionali del Gran Sasso (LNGS)

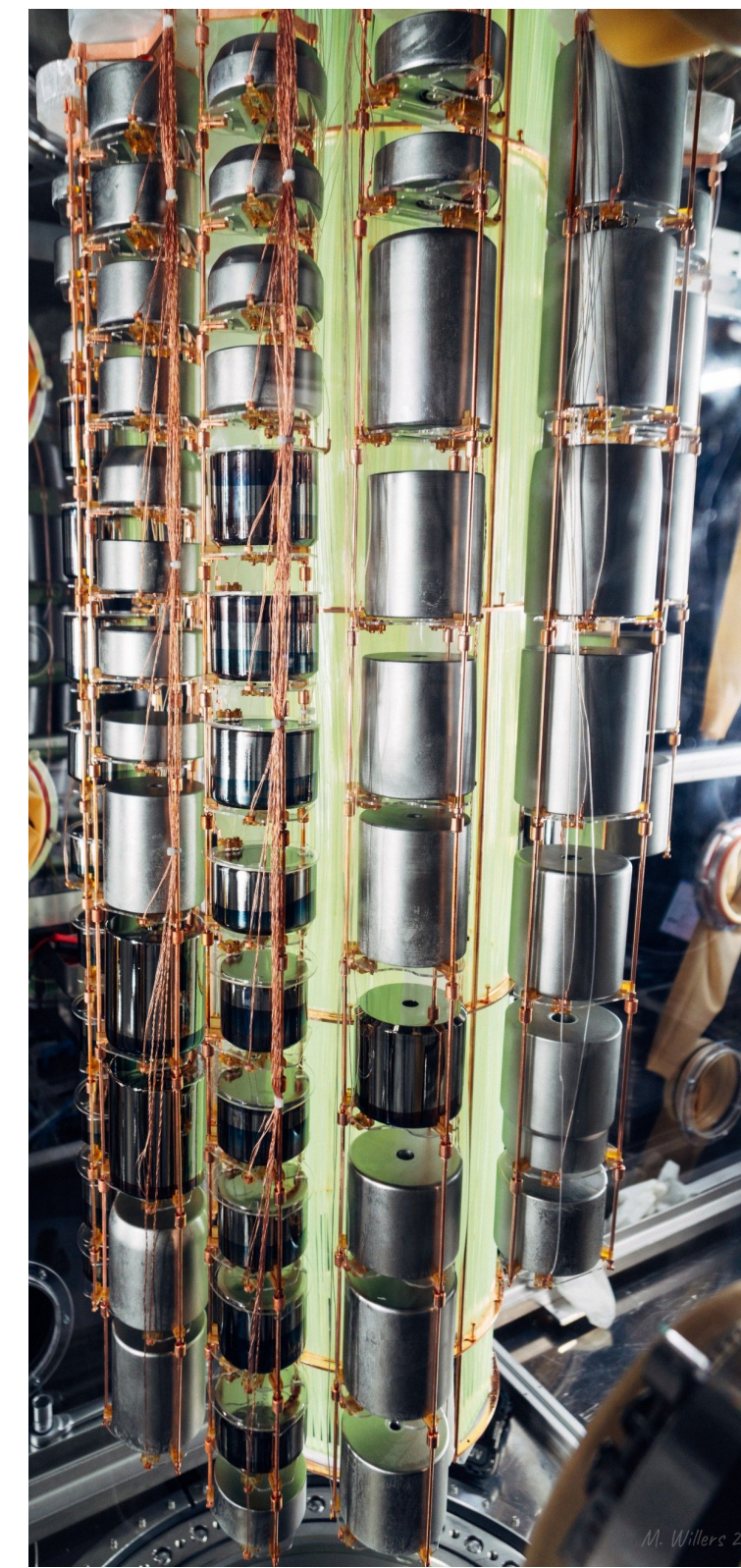


Phase I: LEGEND-200 (This poster)²

- Currently operating with 140 kg of detectors
- Target deployment of 200 kg
- Half-life sensitivity goal: $> 10^{27}$ yr (3σ discovery potential)
- Background goal: $< 2 \times 10^{-4}$ cts/(kg-keV-y)

Phase II: LEGEND-1000³

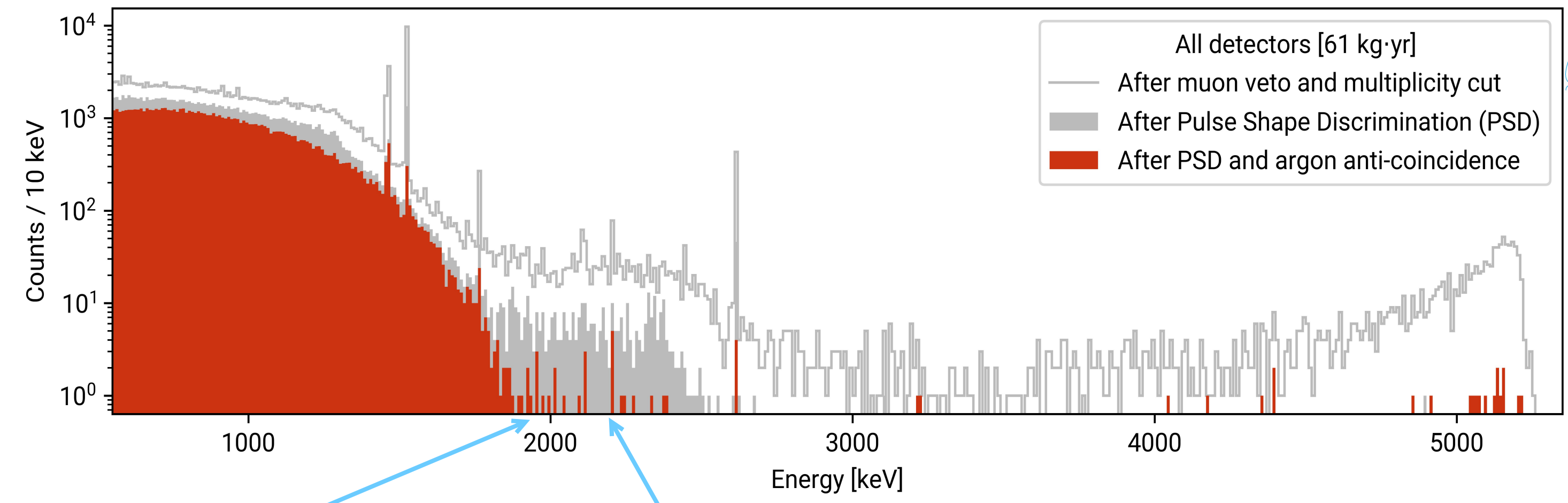
- Deploy 1000 kg of detectors
- Half-life sensitivity goal: $> 10^{28}$ yr (3σ discovery potential)
- Background goal: $< 2 \times 10^{-4}$ cts/(kg-keV-y)
- Successful CD-1 review; seeking funding!



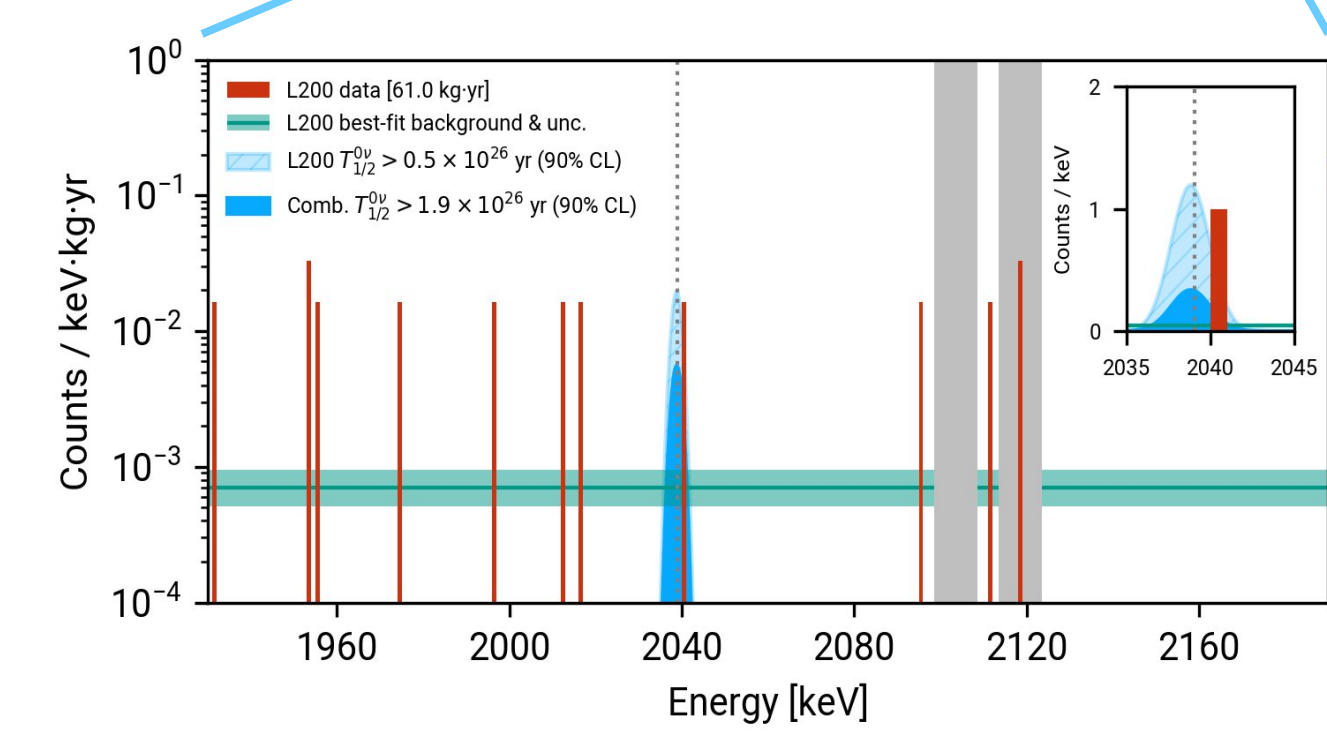
LEGEND-200 detector array before 2023 deployment

First Result from LEGEND-200

First result published in Jan. 2026 with one year of data and 61 kg-yr exposure²



Physics data spectrum from first LEGEND-200 data release. Dominant feature after cuts is $2\nu\beta\beta$



Quasi-Background Free! 11 events in 240 keV analysis window after all cuts

Background index:

Golden dataset (48.3 kg-y): $0.5^{+0.3}_{-0.2}$ cts/keV-kg-y
Silver dataset (12.7 kg-y): $1.3^{+0.8}_{-0.5}$ cts/keV-kg-y

Combined statistical analysis includes LEGEND-200, GERDA, and Majorana Demonstrator datasets
Half-life Limit (90% CL): $T_{1/2} > 1.9 \times 10^{26}$ y
Median Sensitivity (90% CL): $T_{1/2} > 2.8 \times 10^{26}$ y

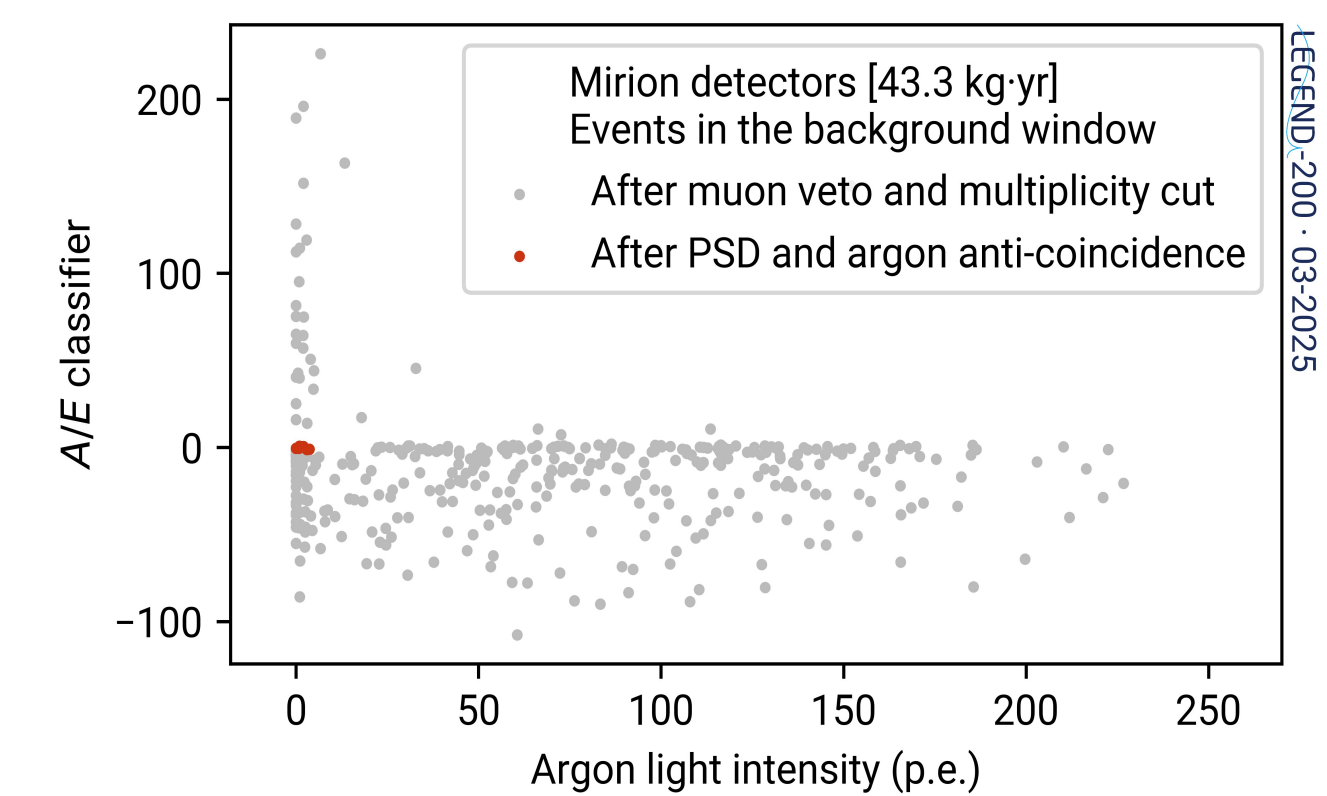
Events in 240 keV wide analysis window after cuts (grey bands excluded Lower half-life limit (90% CL) shown with just LEGEND-200 data and using combined fit

Background Rejection Techniques

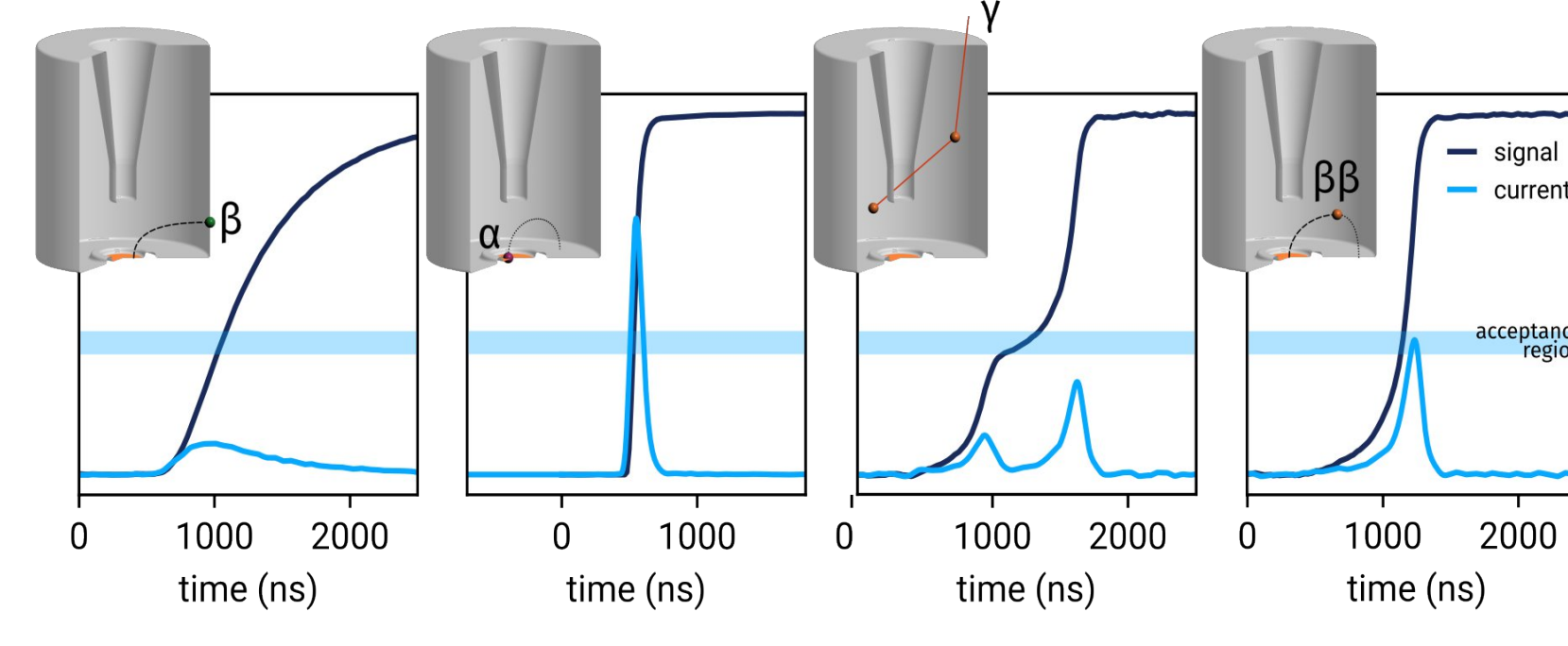
$\beta\beta$ -decay events are localized at decay site and originate in the HPGe detector bulk. We can reject background events with:

- Light detected in liquid argon volume
- HPGe signals with multiple sites
- HPGe signals with slow or fast charge collection due to surface interactions

Background rejection techniques are greater than the sum of their parts!
Combine to **reject ~99% of events in background window!**



Scatter plot of PSD classifier (A/E) vs LAr veto classifier; strong anti-correlation leads to complementarity!



Sample HPGe pulse-shapes for n+ surface (far left), p+ surface (center left), multi-site (center right) and signal-like (far right) events

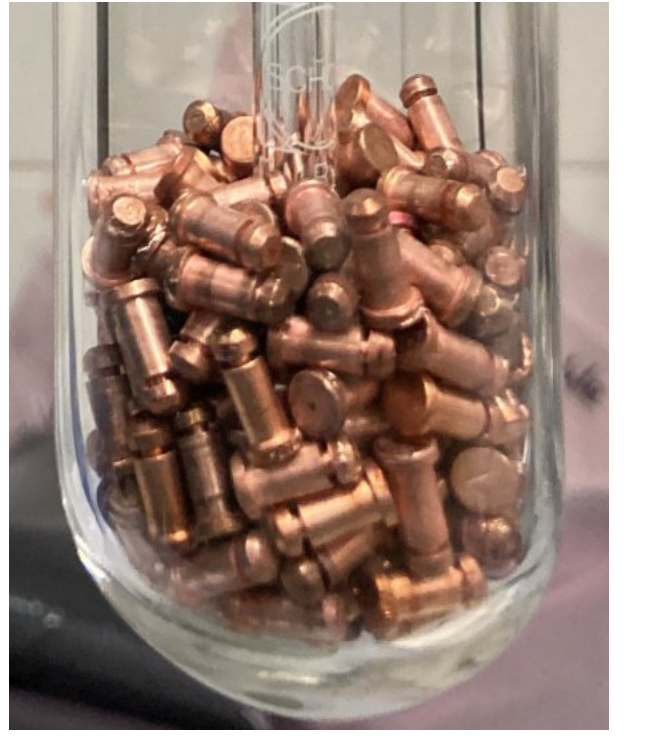
LEGEND-200 Backgrounds

- After termination of first dataset the LEGEND detector array was upgraded
- Replaced old detectors with sub-optimal performance with ICPC detectors (140 kgs after redeployment)
 - Detector characterization measurements performed

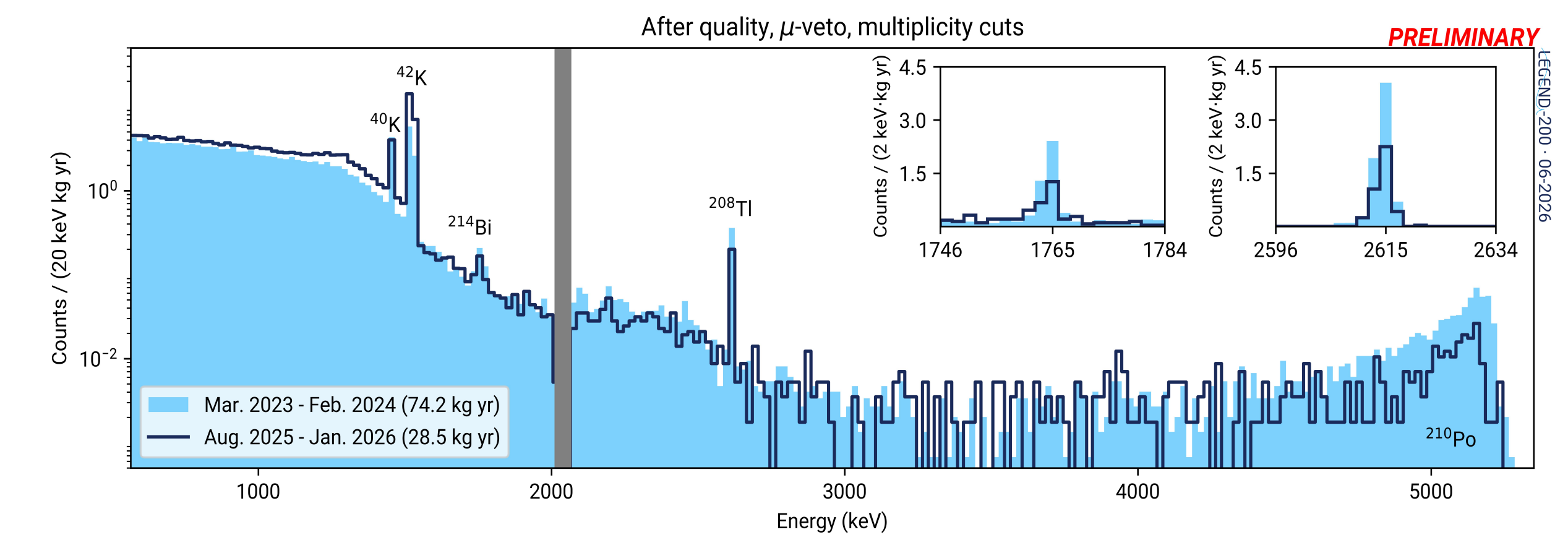
Background studies:

- Background studies in physics data indicated diffuse excess of U/Th
- Detector components re-assayed - elevated U/Th in some components
- Hypothesis: surface contamination

Remedy: **array component surfaces cleaned prior to redeployment**



Rn emanation assay performed on Cu pins



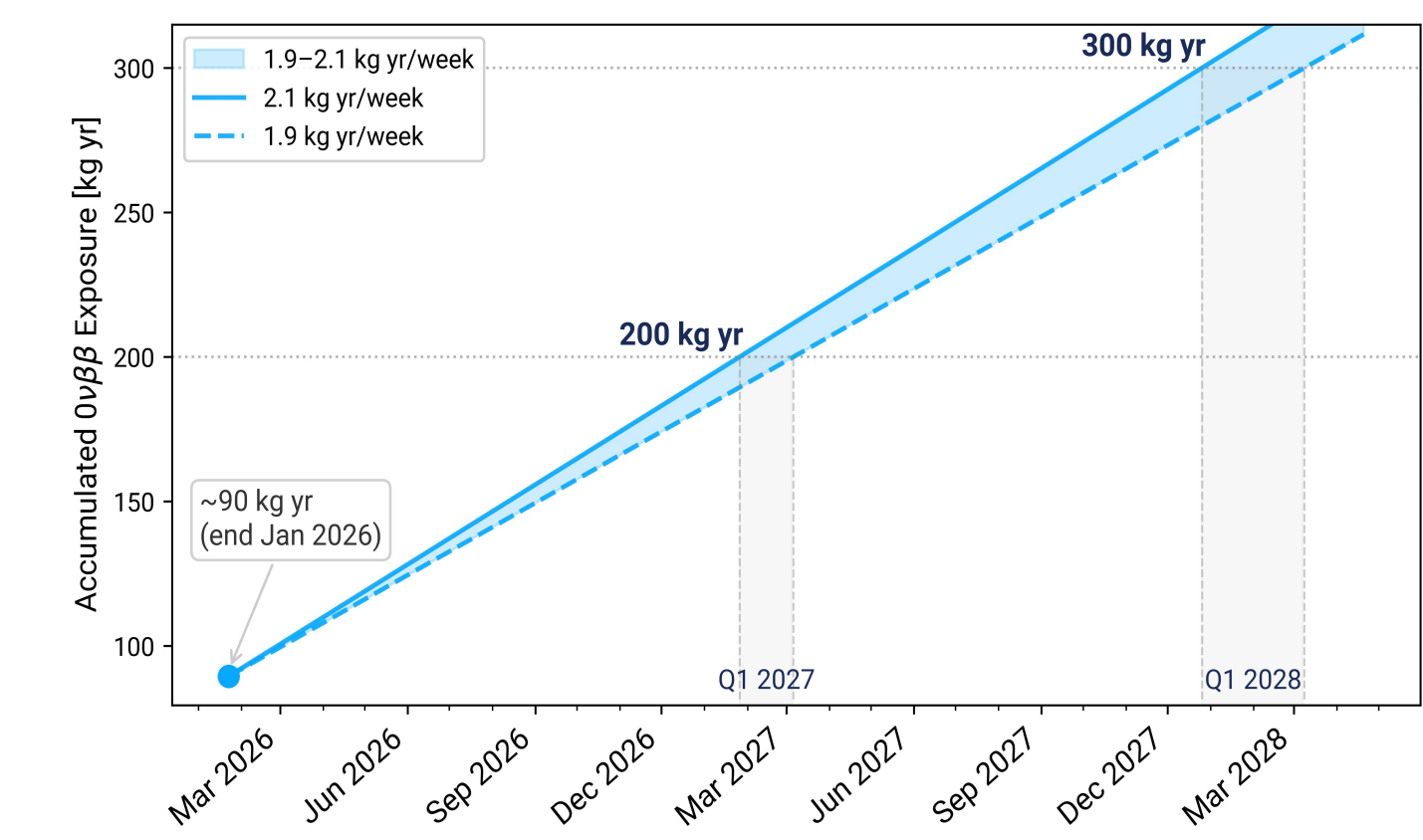
Background spectrum with 32.5 kg-y of exposure (blue) compared to first year of data (black), before PSD and LAr cuts. Reduction in 1764 keV ^{214}Bi line and 2615 keV ^{208}Tl shown in insets

After redeployment, U- and Th-chain γ -lines reduced by a factor of $\sim 2.5\times$

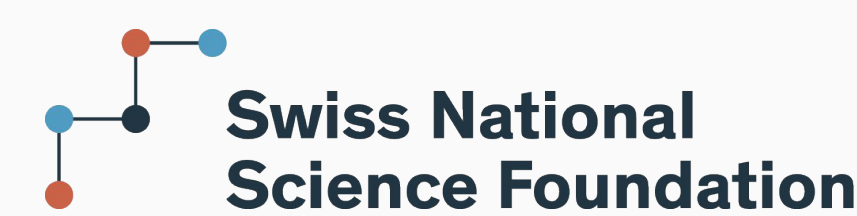
What's next?

LEGEND-200 is collecting data in a stable configuration

- Anticipate 2028 data release
- 200 addition kg-yr of exposure!
 - Improve analysis routines!
 - Double sensitivity!



Expected gain in exposure for the next 2 years



LEGEND Institutions

Centre for Energy, Environmental and Technological Research
Comenius Univ.
Czech Technical Univ. in Prague and IEAP
Daresbury Laboratory
Duke Univ. and Triangle Universities Nuclear Laboratory
Gran Sasso Science Institute
Hochschule RheinMain
Indiana Univ. Bloomington
INFN - Sezione di Napoli
Institute for Nuclear Research Russian Academy of Sciences
Jagiellonian Univ.
Joint Institute for Nuclear Research
Joint Research Centre Geel
Laboratori Nazionali del Gran Sasso

Laboratori Nazionali di Frascati
Lancaster Univ.
Leibniz Institute for Crystal Growth
Leibniz Institute for Polymer Research
Los Alamos National Laboratory
MPI for Nuclear Physics
MPI for Physics
National Research Centre "Kurchatov Institute"
National Research Nuclear Univ. MEPhI
National Taiwan University (NTU)
North Carolina State Univ.
Oak Ridge National Laboratory
Polytechnical Univ. of Milan
Princeton Univ.

Roma Tre Univ. and INFN
South Dakota School of Mines and Technology
Technical Univ. of Dresden
Technical Univ. of Munich
Tennessee Technological Univ.
Univ. of California and Lawrence Berkeley National Laboratory
Univ. College London
Univ. of L'Aquila and INFN
Univ. of Cagliari and INFN
Univ. of California San Diego
Univ. of Houston
Univ. of Liverpool
Univ. of Milan and INFN

Univ. of Milano Bicocca and INFN
Univ. of New Mexico
North Carolina at Chapel Hill
Univ. of Padova and INFN
Univ. of South Carolina
Univ. of South Dakota
Univ. of Tennessee, Knoxville
Univ. of Texas at Austin
Univ. of Tuebingen
Univ. of Warwick
Univ. of Washington and Center for Experimental Nuclear Physics and Astrophysics
Univ. of Zurich
Williams College

References

1. M. Agostini, G. Benato, J. Detwiler, J. Menendez, F. Vissani, *Toward the discovery of matter creation with neutrinoless $\beta\beta$ decay*, Rev. Mod. Phys. **95**, 025002 (2023)
2. H. Acharya, et al. (LEGEND Collaboration), *First Results on the Search for Lepton Number Violating Neutrinoless Double- β Decay with the LEGEND-200 Experiment*, Phys. Rev. Lett. **136**, 022701 (2026)
3. N. Abgrall, et al. (LEGEND Collaboration), *LEGEND-1000 Preconceptual Design Report*, arXiv:2107.11462 (2021)