

Results of the LEGEND-200 background mitigation campaign

Sofia Calgaro

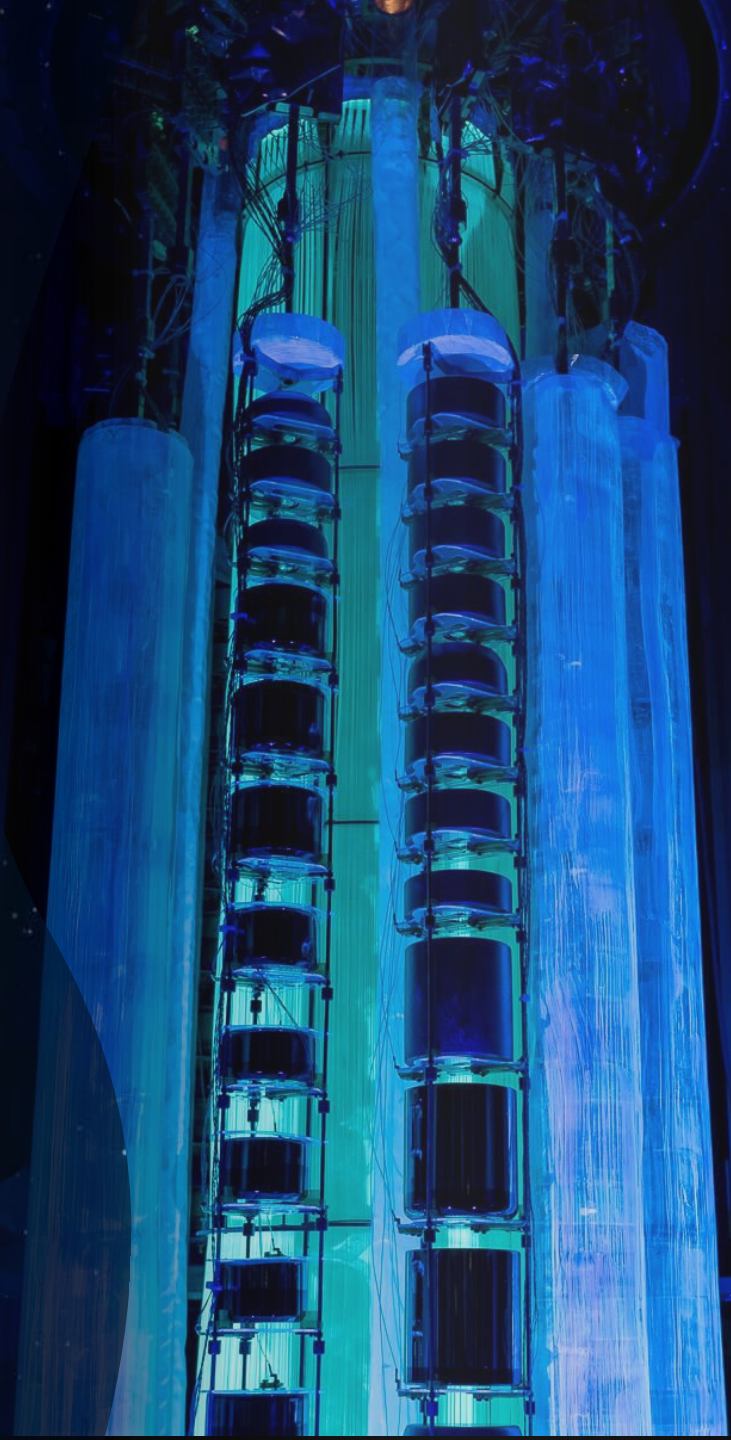
on behalf of the LEGEND Collaboration

Low Radioactivity Techniques Workshop

22 September 2026



University of
Zurich^{UZH}



The LEGEND Project

- **Neutrinoless double beta decay ($0\nu\beta\beta$)** is a hypothetical nuclear transition in even-even nuclei where no neutrinos would be emitted; **possible if neutrinos are Majorana particles**
- The LEGEND (Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay) Collaboration aims to develop a phased, ^{76}Ge -based $0\nu\beta\beta$ decay program with **discovery potential at $T_{1/2}^{0\nu} > 10^{28}$ yr** [10.48550/arXiv.2107.11462]
- Collaboration formed in 2016, building on the expertise of GERDA  and Majorana DEMONSTRATOR  experiments; search for $^{76}\text{Ge} \rightarrow ^{76}\text{Se} + 2e^-$ at $Q_{\beta\beta} = 2039.061$ (7) keV [Phys. Rev. C 81, 032501 (2010)]



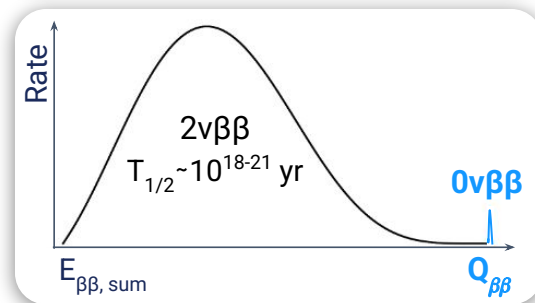
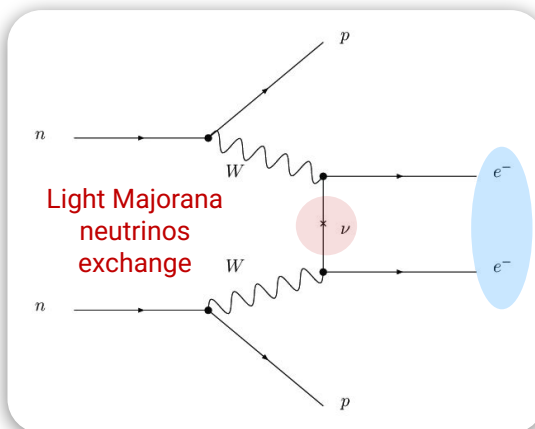
13 countries, 60 institutions, ~350 members



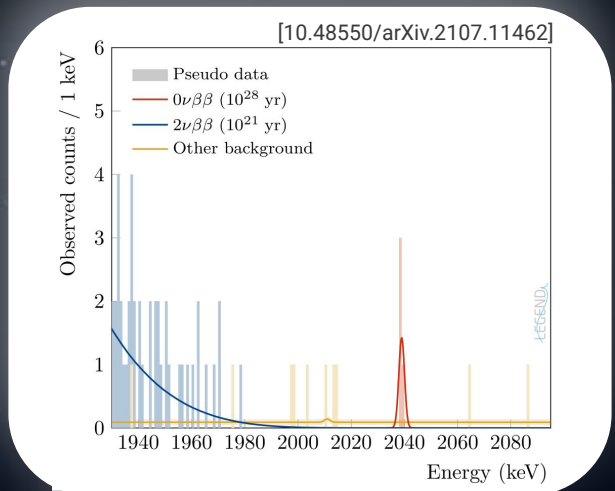
MINISTRY OF EDUCATION
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Swiss National
Science Foundation

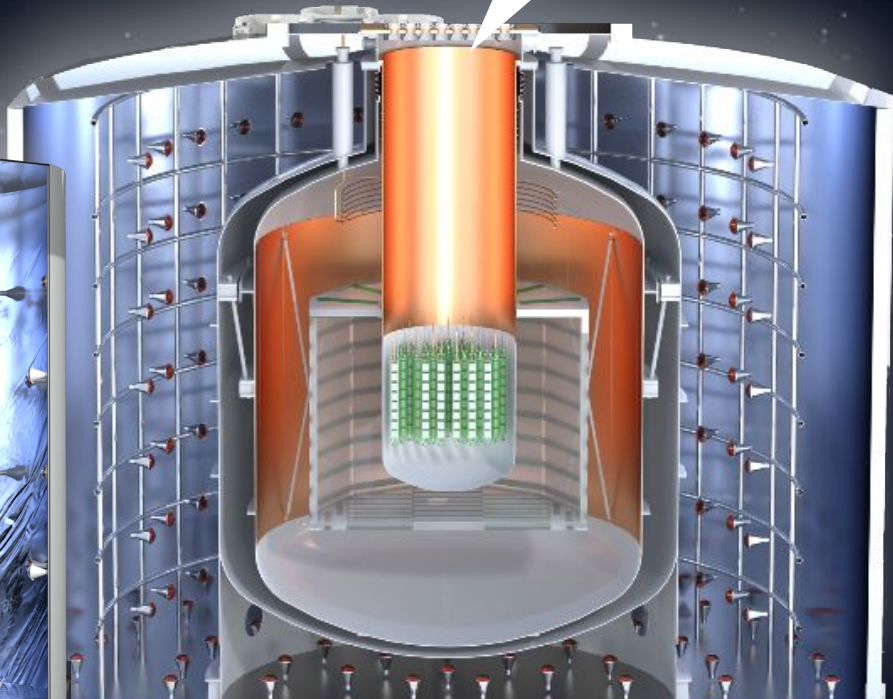
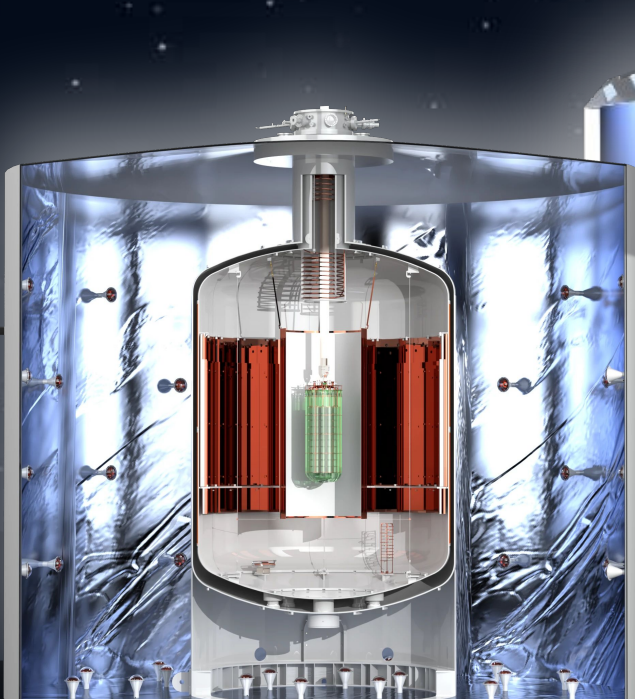


Mass capacity	200 kg	→ 5x →	1000 kg
Target exposure	1 ton yr (5 yr)	→ 10x →	10 ton yr (10 yr)
Resolution in FWHM	2.5 keV		2.5 keV
Background [cts/(keV ton yr)]	0.2	→ 0.05x →	0.01
$T_{1/2}^{0\nu}$ sensitivity	10^{27} yr	→ 10x →	10^{28} yr
Current status	Taking data		Under construction



R. Biondi, "The way to zero background search with LEGEND-1000", poster

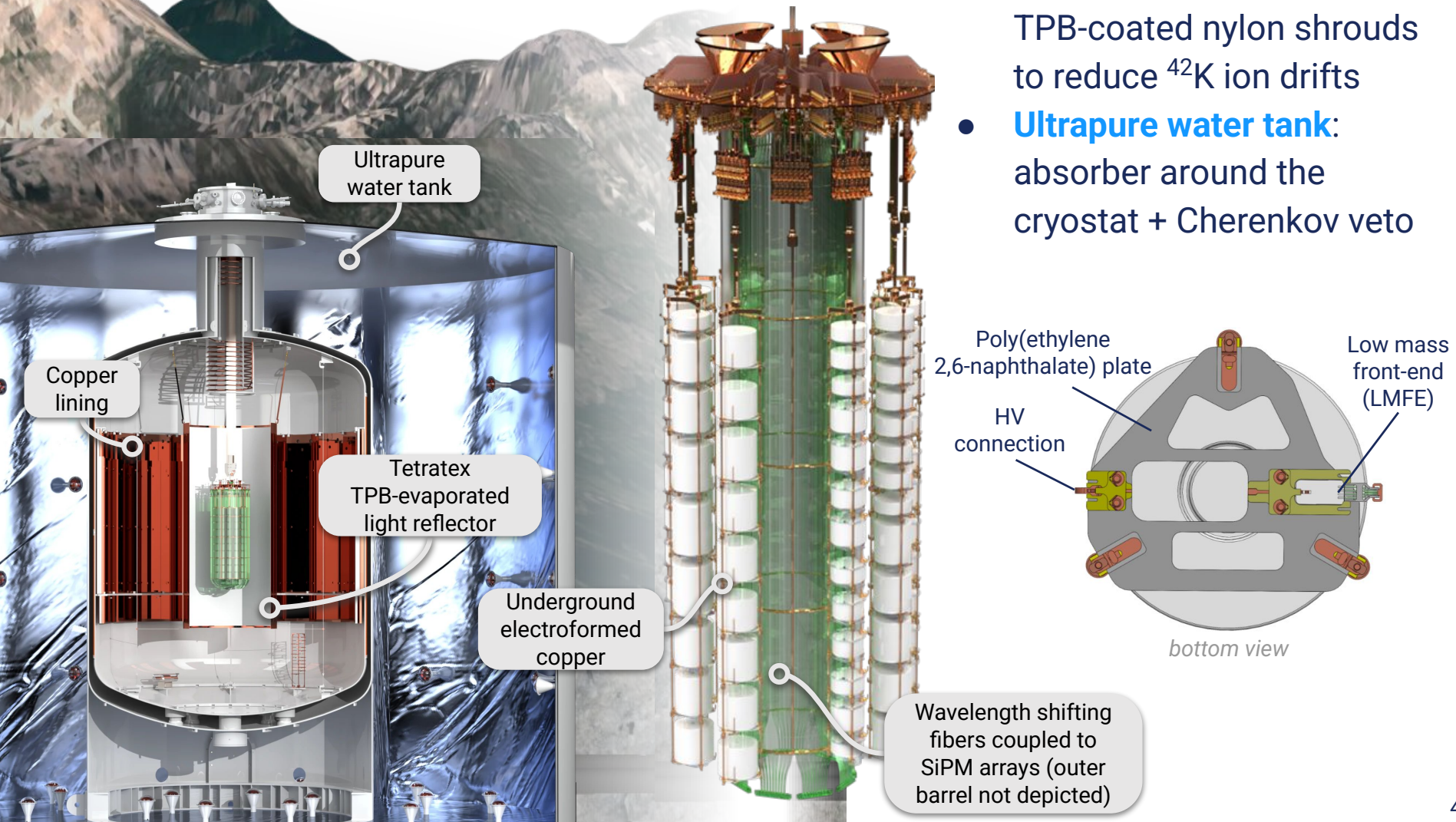
M- Neuberger, "Delayed Coincidence Based Active Suppression of In-Situ Muon-Induced Isotope Backgrounds in LEGEND", poster



LEGEND-200

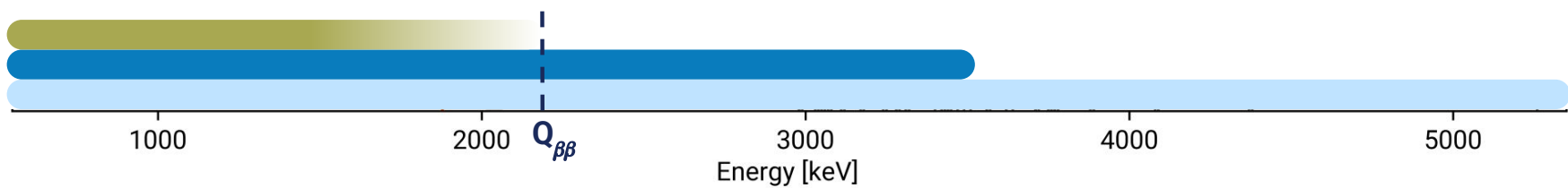
- **Overburden of 3500 mwe** ($R_{\mu} \sim 1.25/\text{m}^2\text{h}$)
- First deployment (Mar. 2023- Feb. 2024): 142 kg of ^{76}Ge -enriched **p-type HPGe diodes** mounted on low-mass holders **immersed in LAr** (cryogenic coolant, active veto)

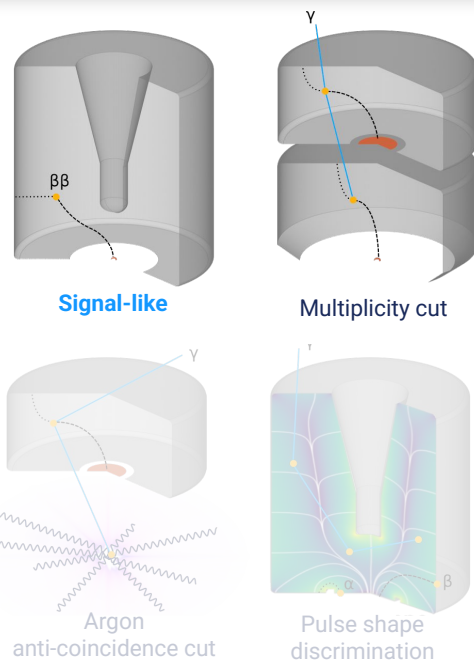
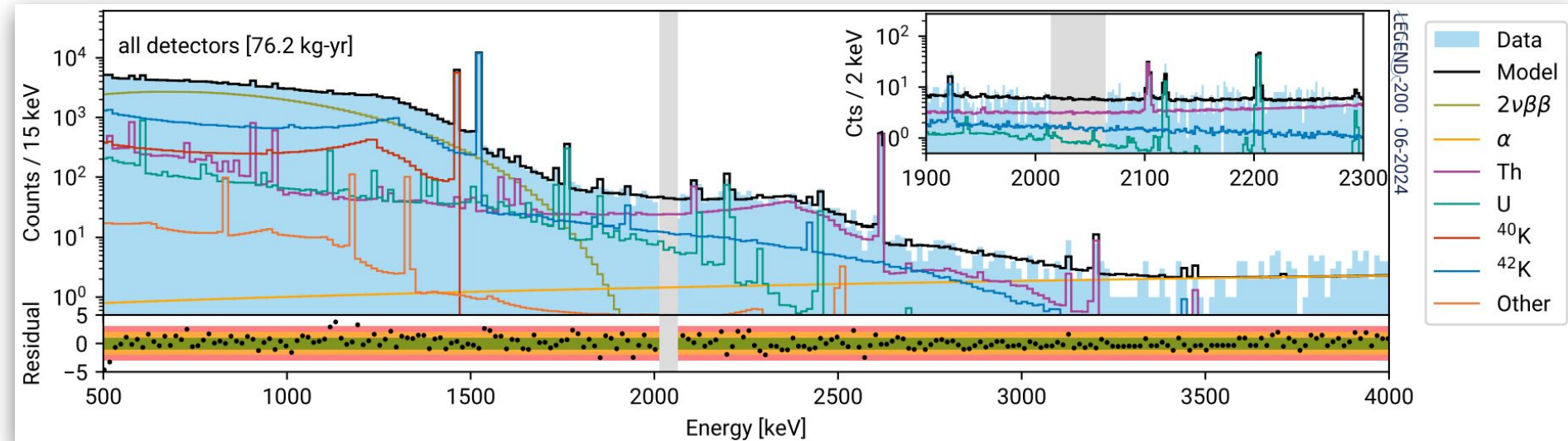
- HPGe strings surrounded by TPB-coated nylon shrouds to reduce ^{42}K ion drifts
- **Ultrapure water tank:** absorber around the cryostat + Cherenkov veto



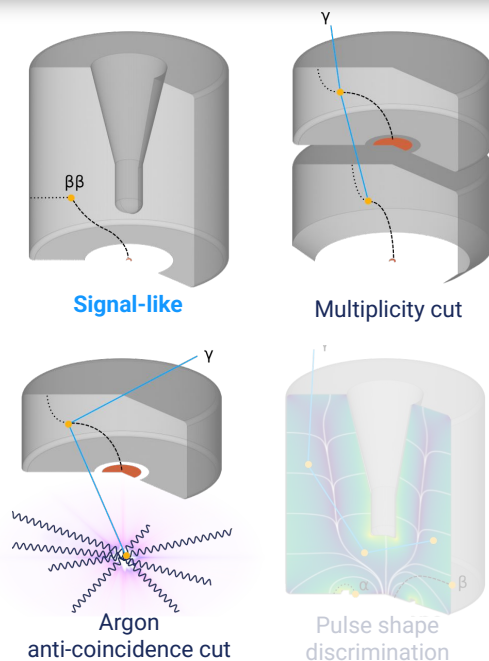
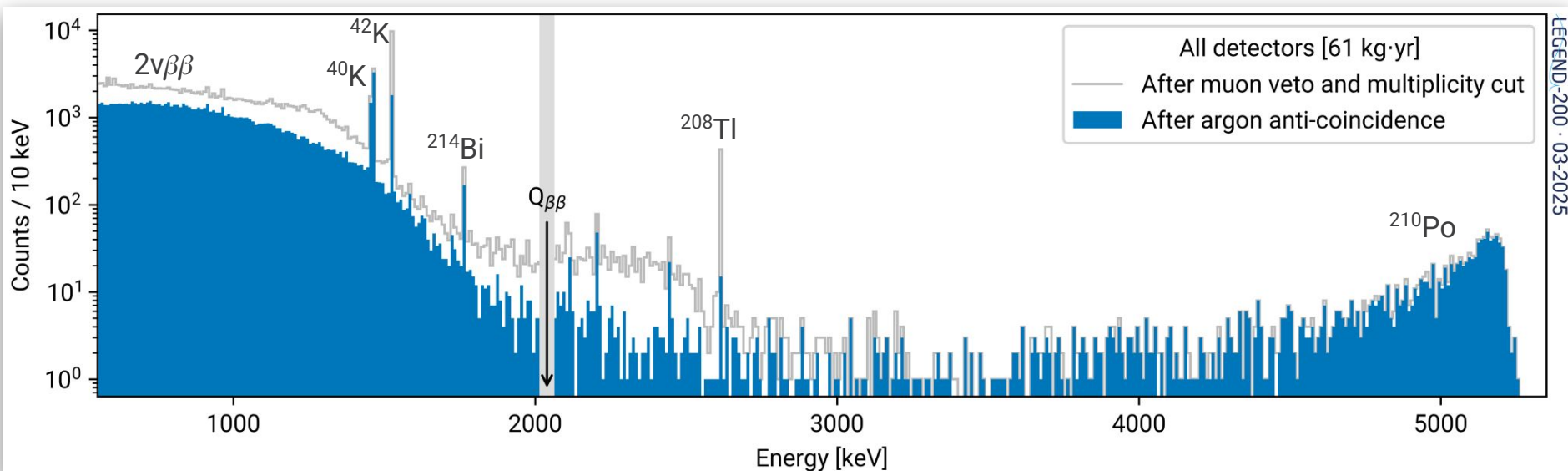
Background Components

Background	Origin	Signature in Ge	Comments	Mitigation
2vββ decay	Ge detectors	Continuous spectrum, dominant below 1.5-1.7 MeV	Intrinsic background	Excellent energy resolution: 0.1-0.2% FWHM at $Q_{\beta\beta}$ (energy bias of 0.2 ± 0.3 keV) [10.48550/arxiv.2605.22479, accepted by EPJC]
$^{42}\text{Ar}/^{42}\text{K}$ in LAr	LAr volume; ^{42}K can drift toward detector surfaces	High energy γ and β from ^{42}K decay ($Q_{\beta}=3.5$ MeV)	No information available from screening; spatial distribution difficult to model	LAr veto; PSD cut; nylon mini shrouds around Ge strings
Natural radioactivity ^{232}U , ^{238}Th , ^{40}K	Detector and structural materials (bulk, surface)	High energy γ and β/α	Relevant across the ROI; μBq activities can matter	Radiopure materials; Ge diodes granularity; LAr veto; PSD cut; passive shields
Cosmogenic activation	Ge and detector/material components exposed above ground	β/γ from cosmogenic isotopes; short- and long-lived isotopes	Negligible for L-200	Underground operations; controlled material handling; dedicated veto in L-1000

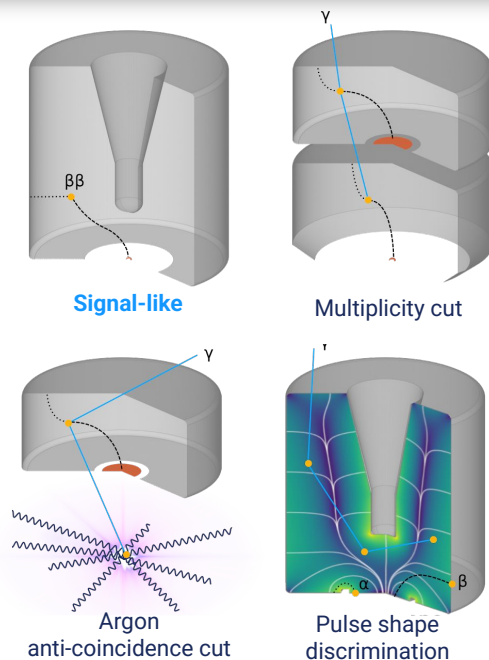
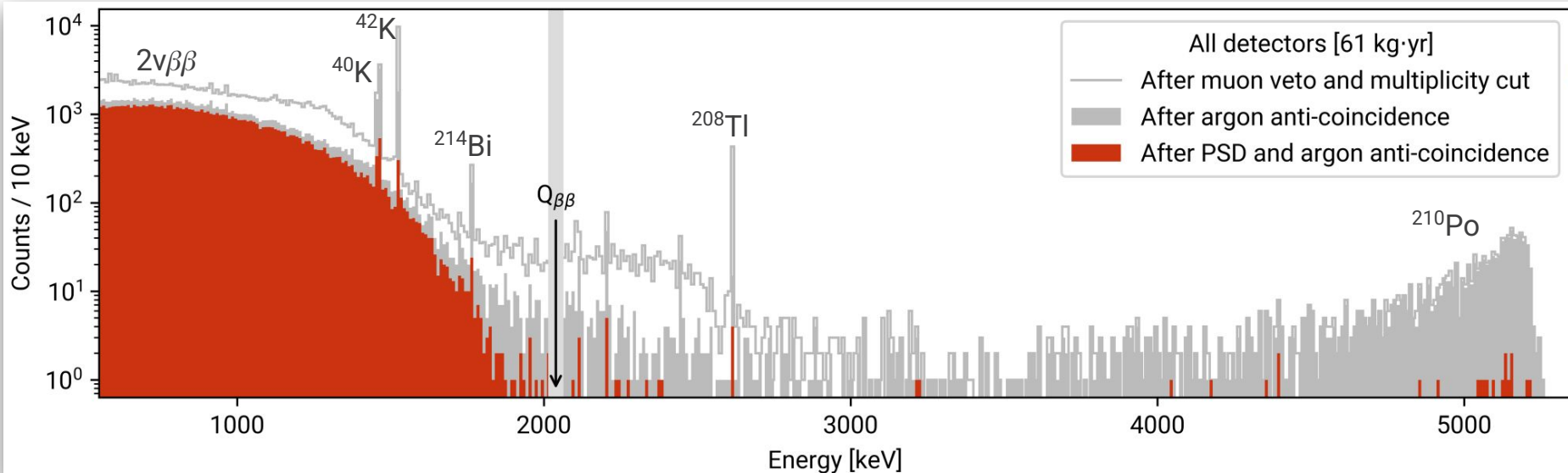




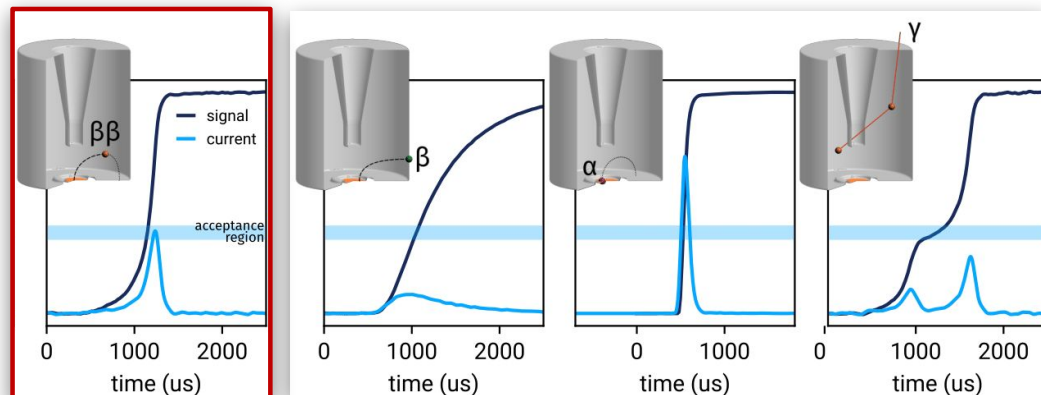
✂ Gamma coincident emission



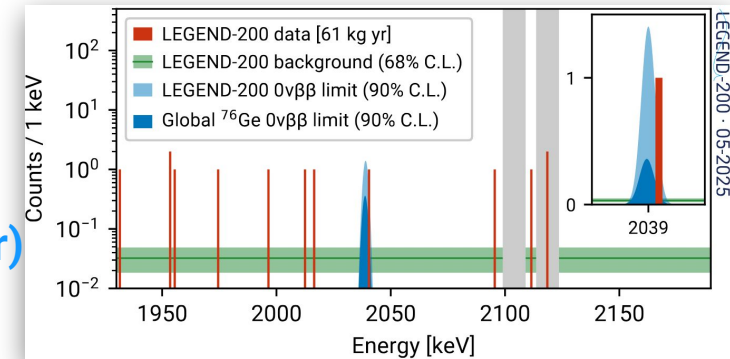
✂ Gamma coincident emission



- ✂ Gamma coincident emission
- ✂ Multi Compton, FEP, SEP, surface α/β

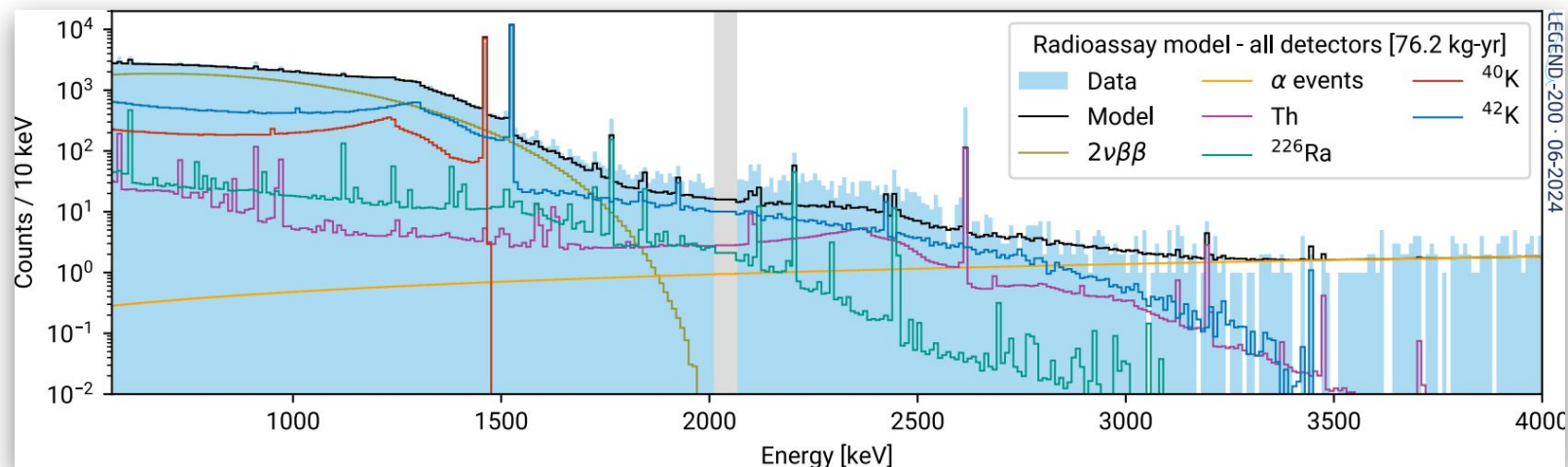


- GERDA+MJD+LEGEND-200 combined analysis:
 - observed limit: $T_{1/2}^{0\nu} > 1.9 \times 10^{26} \text{ yr @ 90\% CL/CI}$
 - world-leading sensitivity: $2.8 \times 10^{26} \text{ yr}$
- **Golden dataset (48 kg yr):** $BI = 0.5^{+0.3}_{-0.2} \text{ cts}/(\text{keV} \cdot \text{ton} \cdot \text{yr})$
- **Silver dataset (13 kg yr):** $BI = 1.3^{+0.8}_{-0.5} \text{ cts}/(\text{keV} \cdot \text{ton} \cdot \text{yr})$



Simulations and material radioassay underpredicted data

- ⚠ Some sources only have ICP-MS measurements
- ⚠ Possible breaking of secular equilibrium in U/Th chains
- ⚠ Systematics on assay values are hard to estimate

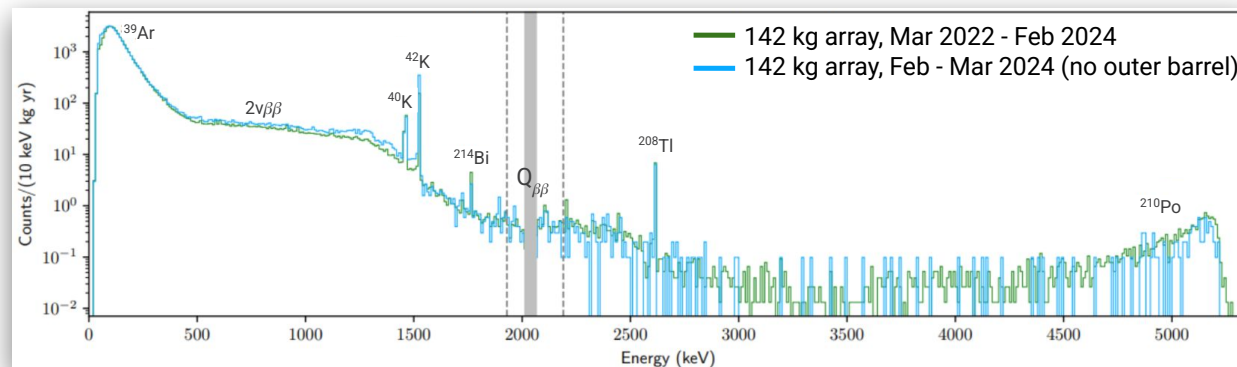


[T. Dixon, "Analysis of the backgrounds in the LEGEND-200 experiment", LRT24](#)

[L. Varriano, "Radioassays for the LEGEND 76Ge 0νbb search", LRT24](#)

In-situ Self Assaying

- Feb.-Apr. 2024: data taken with **two special configurations with components removed for *in-situ* self-assaying**
 - outer barrel** (10.2 kg yr): $\sim 50\%$ of ^{238}U contamination could be explained via insufficient Cu cleaning; assays indicated several tens of μm had to be etched
 - nylon mini-shrouds** (5.9 kg yr): $^{238}\text{U}/^{232}\text{Th}$ contaminations are consistent with before, but with large uncertainties (low exposure, higher ^{42}K background)
- Inspected γ rates and spatial distributions, LAr veto suppression and MC-data agreement, **exploiting Ge-array granularity to localize contaminations**
 - 1-diode hits: compatible with close/intermediate sources;
 - 2-diodes hits: excludes strong contamination on very close parts



Nylon mini-shrouds surrounding Ge strings (B)

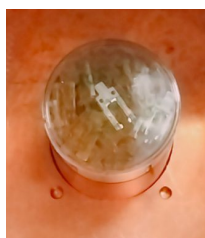
Outer Cu barrel supporting WLSR fibers (A)

Forensic Campaign

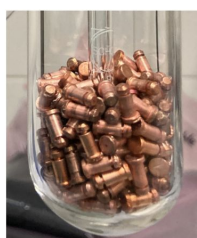
- **Apr. 2024 - Jul. 2025: extensive material screening*** → elevated activities identified in **detector base-plate assemblies** (PEN, Ultem, Cu pins, phosphor-bronze springs) + **WLS fibers**
- MC simulations suggest they largely explain the elevated $^{214}\text{Bi}(^{238}\text{U})$ and $^{208}\text{Tl}(^{232}\text{Th})$
- Raw materials met cleanliness requirements; **surface contamination introduced during machining/handling/cleaning**
- Replaced/reused components underwent enhanced cleaning protocols and comprehensive quality assurance procedures before the latest array installation (**all materials were produced from screened raw materials**)



Poly(ethylene
2,6-naphthalate) plate

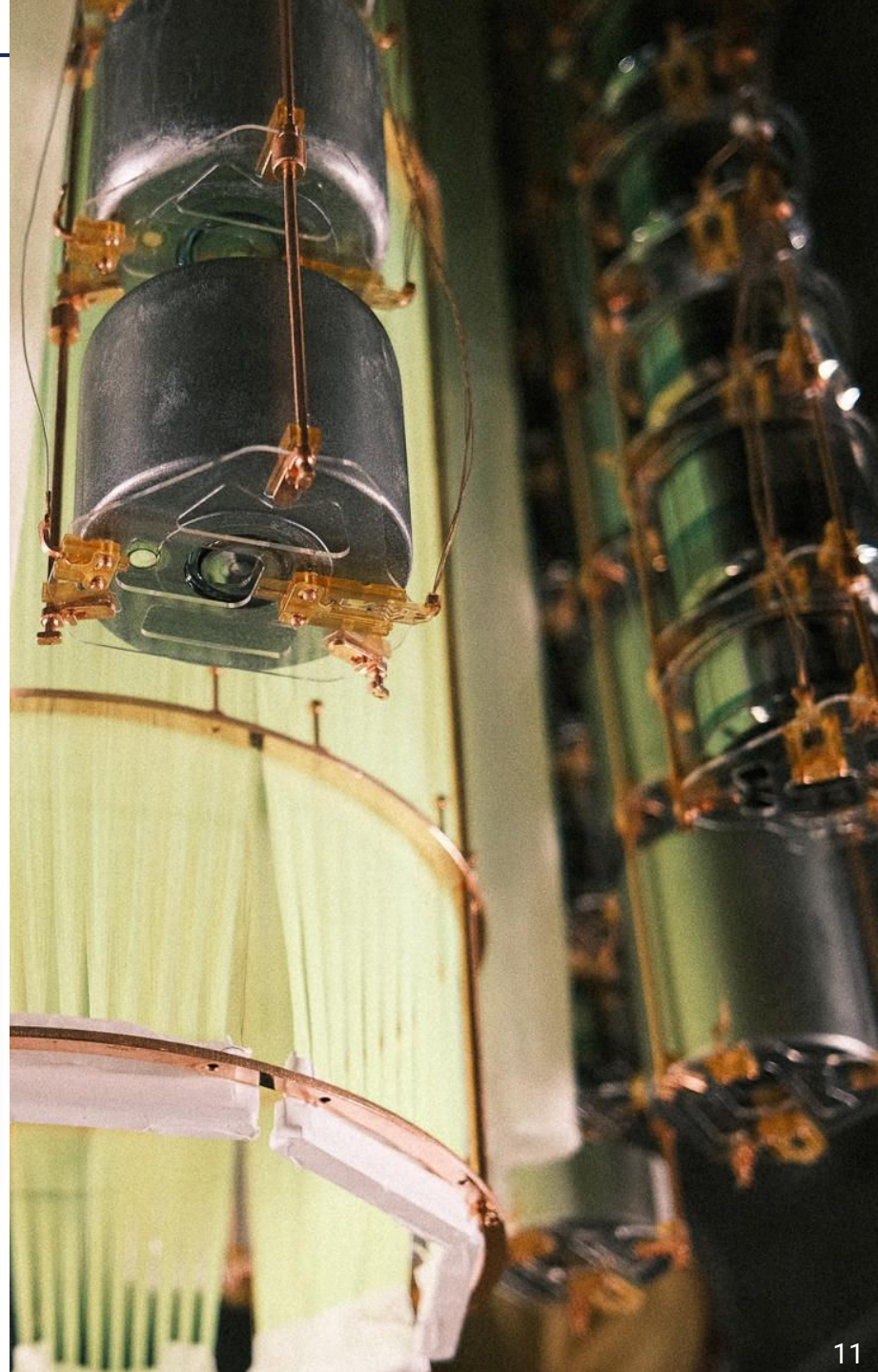


Ultem γ
assay



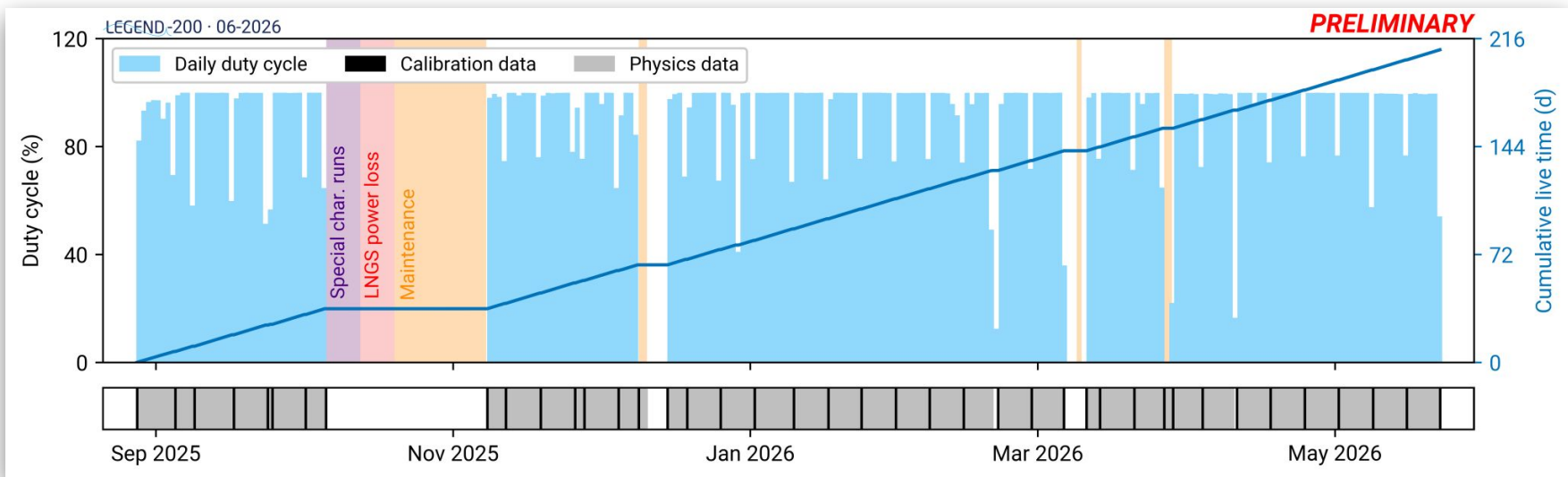
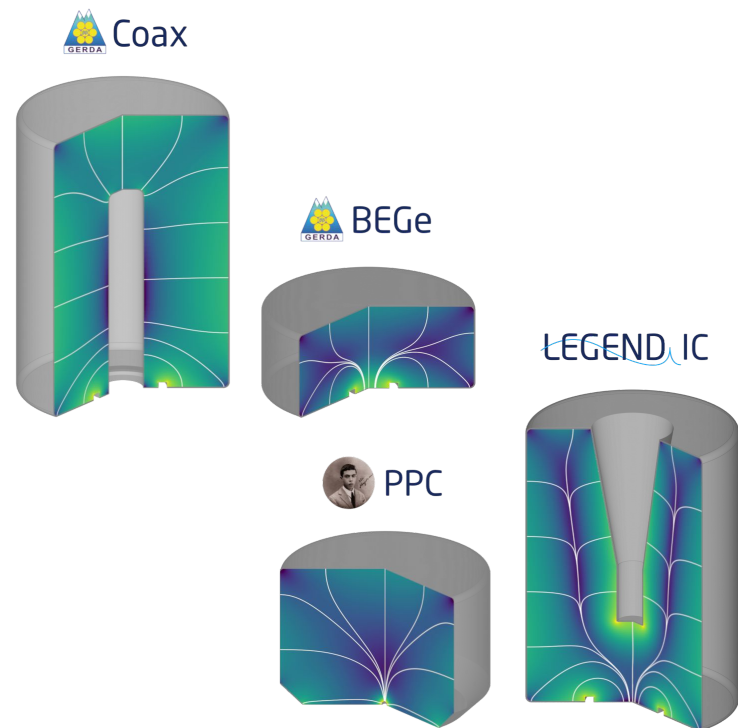
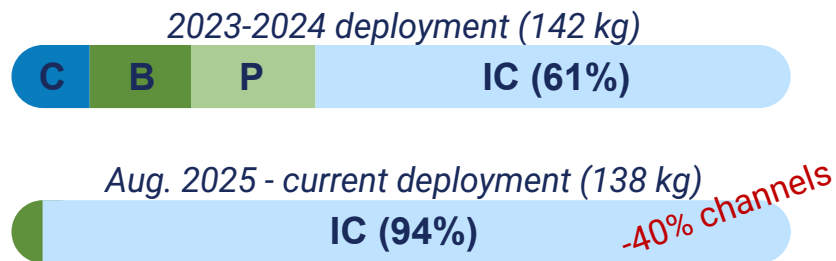
Cu pins Rn
emanation assay

* γ screening @ GeMPI, Gator (LNGS) / HADES / Boulby / GeRysy (LSC), α spectroscopy @ Jagiellonian University, radon emanation @ MPIK

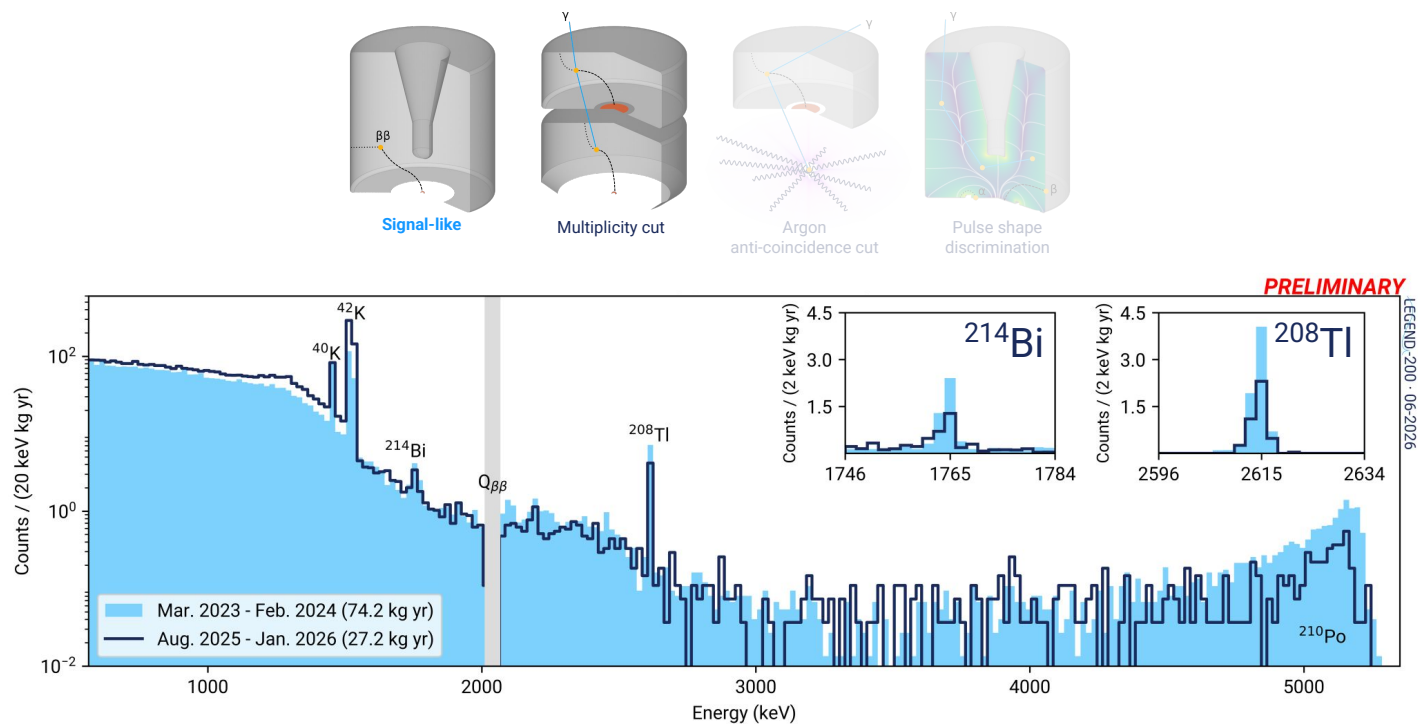


The 2025 Deployment

- **August 2025: 138 kg deployed**, after converting COAX/PPC/BEGe/underperforming detectors
- **Stable physics data taking** since August 2025
 - 93% duty cycle without downtimes

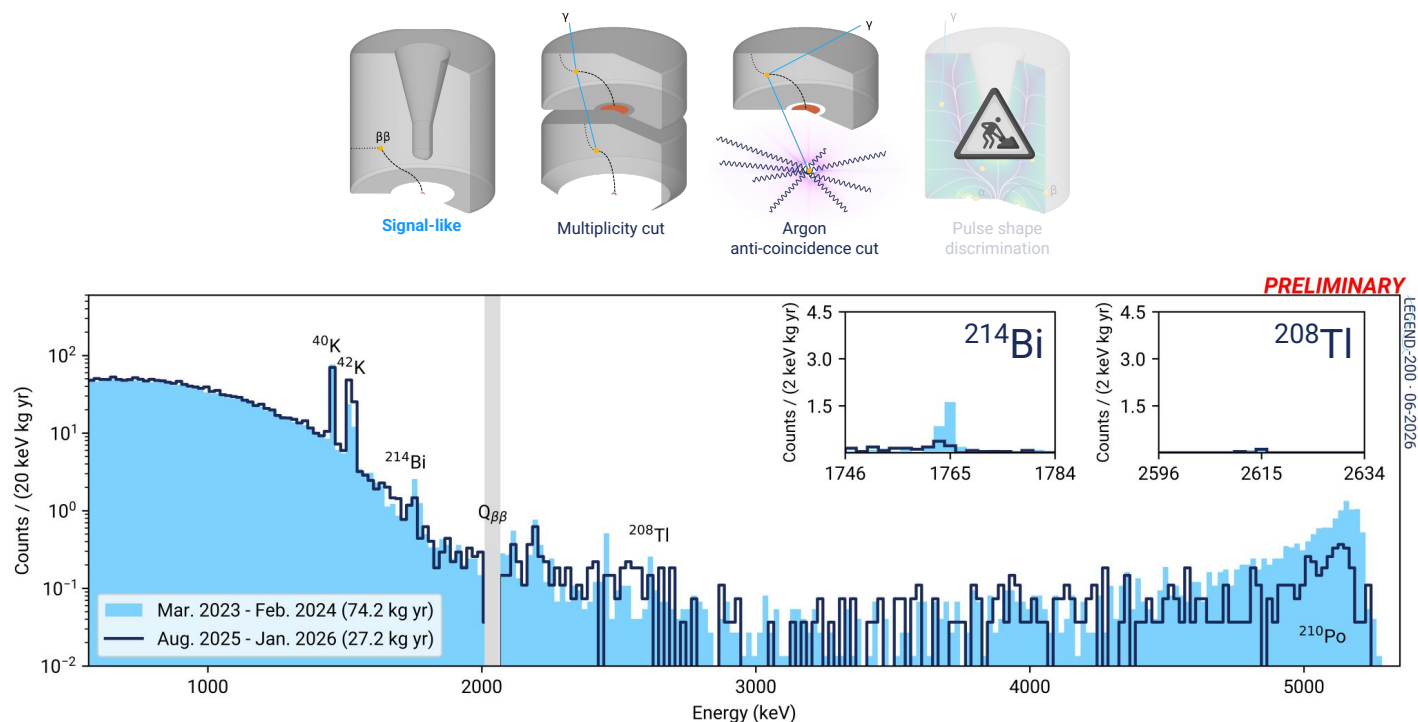


Background Before Cuts



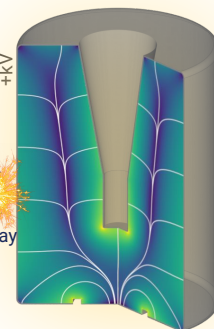
- **Validated new data up to the end of January 2026 (27.2 kg yr)**
- Removal of large p+ contact detectors (COAX) resulted in a reduction of α events
- Higher ^{42}K 1.5 MeV γ content; affected by ion drift in electric fields, detectors bias voltages and geometry, presence of shields, ...; decreases with time, while $Q_{\beta\beta}$ continuum remains constant
- $^{214}\text{Bi}(^{238}\text{U})/^{208}\text{Tl}(^{232}\text{Th})$ reduced by ~ 2 before cuts
 - preliminary **y** count rate is compatible with the new assays predictions

Background After Cuts



- **Rates after LAr veto compatible with the removal of surface contamination**
 - 5x overall reduction of ^{214}Bi 1764 keV γ -line, ^{208}Tl ~eliminated
- **Proves effectiveness of cleaning campaign**
- Residual background after cuts appears to be dominated by ^{42}K surface events
 - **dedicated ^{42}K task force** coordinating efforts to address this background
 - optimization of rejection analysis methods, e.g. joint PSD cuts
- **^{42}K background expected to be mitigated in LEGEND-1000**

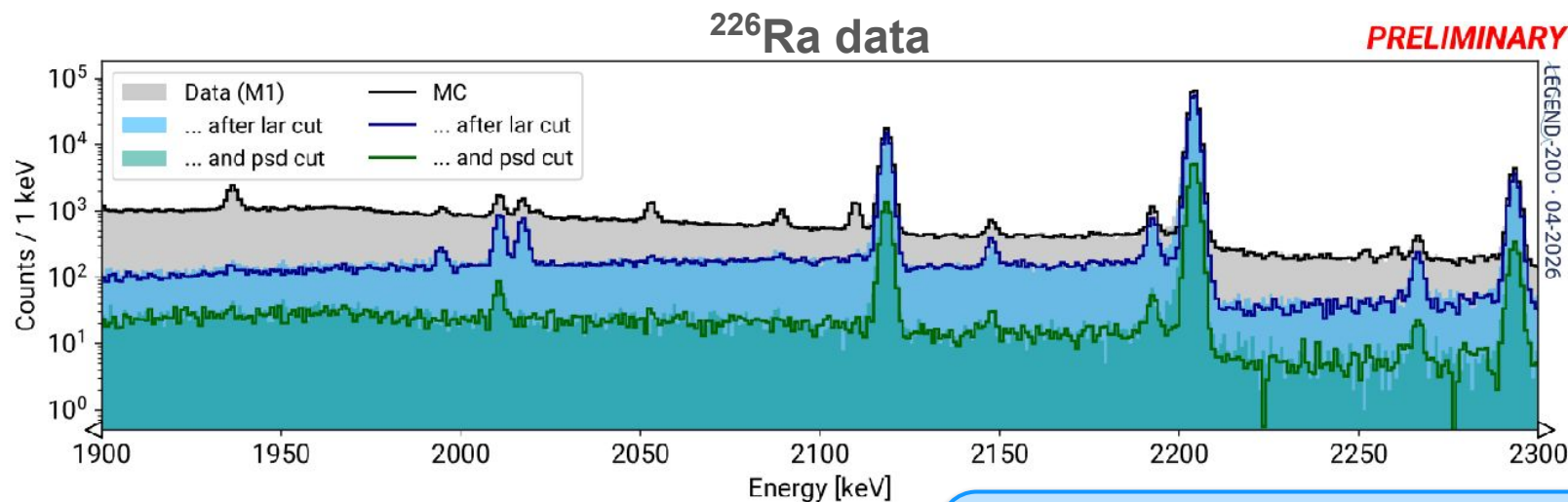
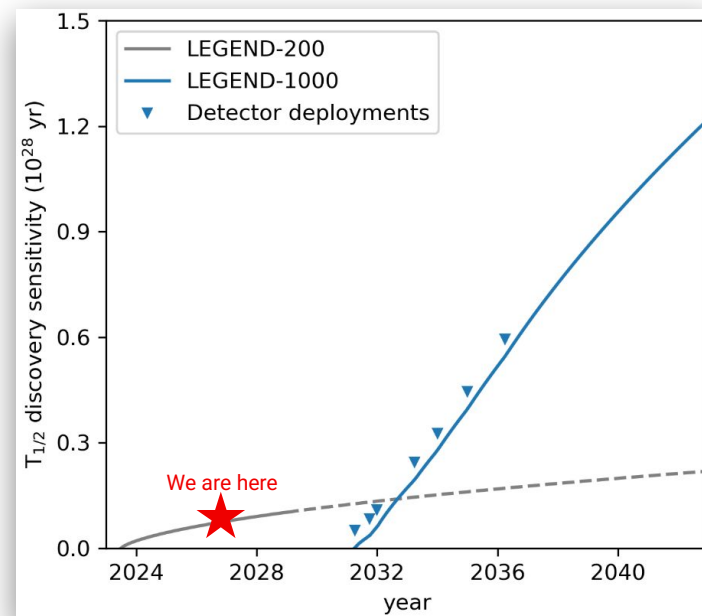
^{42}Ar β decay
↓
 ^{42}K ions
drift towards n+ contact



C. Vogl, "K-42 mitigation studies in Ar-42 spiked liquid argon for LEGEND", talk

Next Steps

- Maximize exposure collection while building background model & radioassay material interpretation for >2025 data
- Ongoing work for modeling *in-situ* special characterization data (^{228}Th , ^{226}Ra) after cuts
- LEGEND-200 provides a test bed for technology development and risk reduction for the tonne phase



L. Pertoldi, "remage: a modern simulation framework for low-background physics experiments", poster

Summary

- **World-leading $0\nu\beta\beta$ sensitivity** with 142 kg of ^{76}Ge
- **Higher-than-expected background source likely identified** via assay and cleaning campaign in close-by components to HPGe diodes (2024-2025)
- Ongoing validation of data collected since August **2025 deployment (94% IC detectors)**
- **Leading experiment** until LEGEND-1000 comes online ($0\nu\beta\beta$ quasi-free background decay search with discovery sensitivity beyond 10^{28} yr)
- **Advanced background-mitigation strategies** under development for the tonne phase
- Data taking is expected to start in the early 2030s

Thank You!

