March 04, 2026, LLWI 2026,
Lake Louise, Alberta, Canada

Probing neutrino nature:

First results from LEGEND-200 experiment in search for neutrinoless double beta decay

HARISREE KRISHNAMOORTHY

PHYSICS DIVISION, OAK RIDGE NATIONAL LAB

On behalf of the LEGEND collaboration

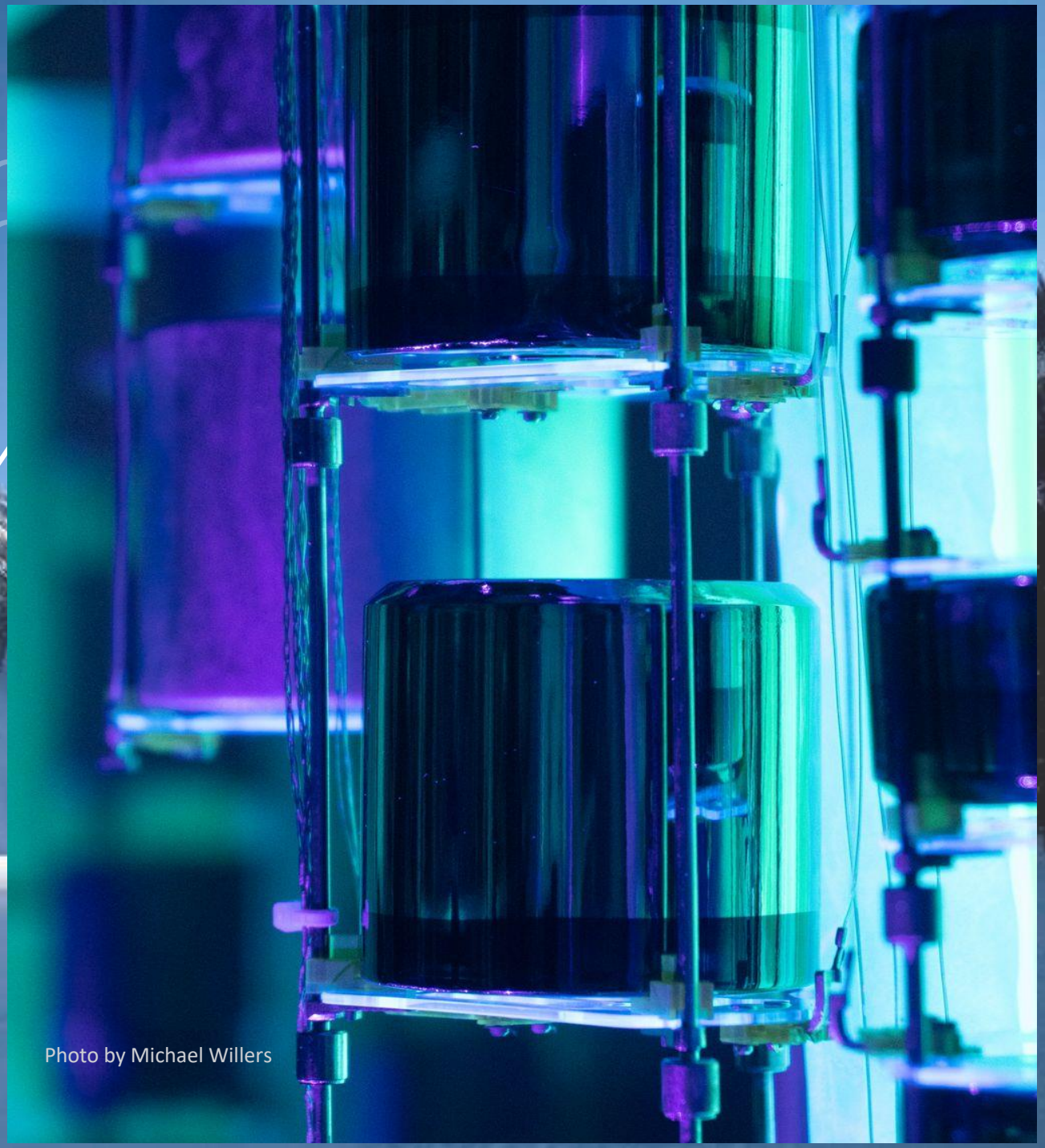


Photo by Michael Willers

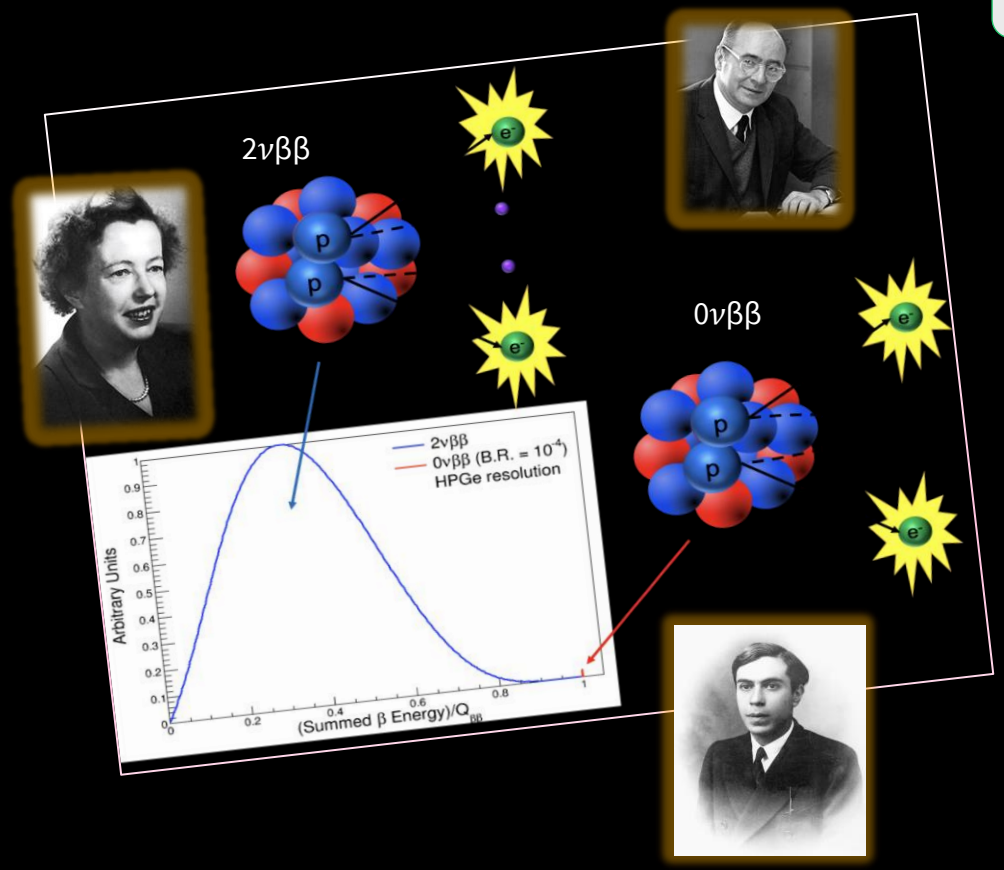
The LEGEND Collaboration

11 countries, ~60 institutions, ~300 members..

Large Enriched Germanium Experiment for Neutrinoless ββ Decay

LEGEND mission:
The collaboration aims to develop a phased, ^{76}Ge-based double-beta decay experimental program with discovery potential at a half-life beyond 10^{28} years, using existing resources as appropriate to expedite physics results

Neutrinoless double beta decay ($0\nu\beta\beta$) is an excellent (and perhaps the only) probe to Majorana nature of neutrinos



Implications if $0\nu\beta\beta$ is observed (assuming light ν exchange)

- Neutrinos are Majorana fermions
- B-L is not conserved ($\Delta L=2$), $m_{\beta\beta} \neq 0$
- Absolute neutrino mass scale can be constrained

$$(T_{1/2})^{-1} = G_{0\nu} \times |M_{0\nu}| \times (m_{\beta\beta}/m_e)^2$$

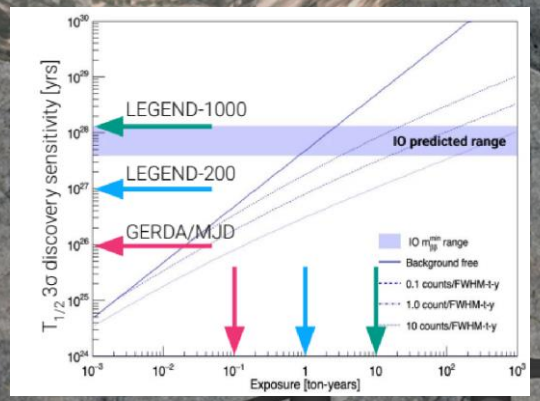
LEGEND - 200

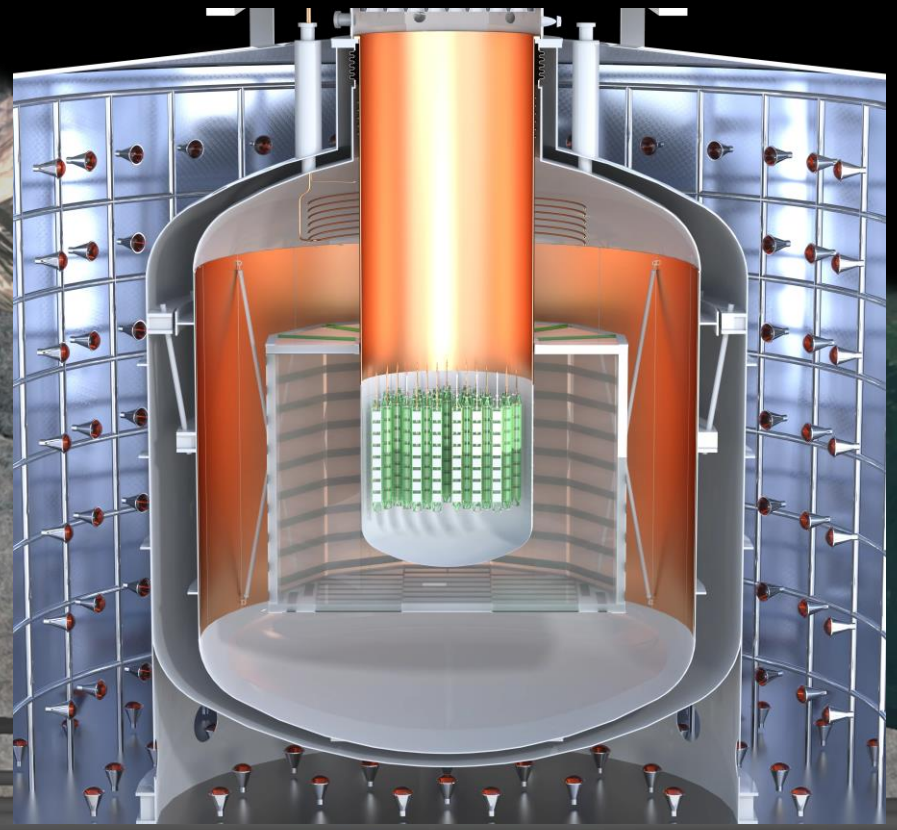
LEGEND - 1000

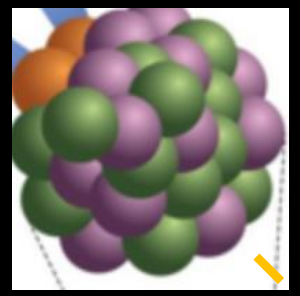
LEGEND - 200		LEGEND - 1000
200 kg (x 5 yr) enriched Ge	Exposure goal	1000 kg (x 10 yr) enriched Ge
2×10^{-4} cts/(keV kg yr)	Background goal	$< 10^{-5}$ cts/(keV kg yr)
$T_{1/2}(0\nu) > 10^{27}$ yr	Half-life sensitivity	$T_{1/2}(0\nu) > 10^{28}$ yr
m ~ 30 - 70 meV	Absolute neutrino mass range	m ~ 10 - 20 meV

@LNGS Hall A

3600 m.w.e

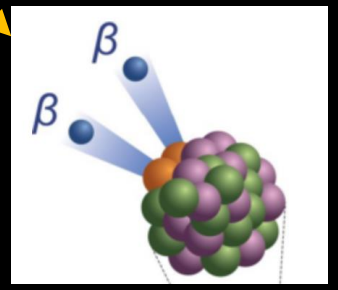






^{76}Ge

Q-value = 2039 keV



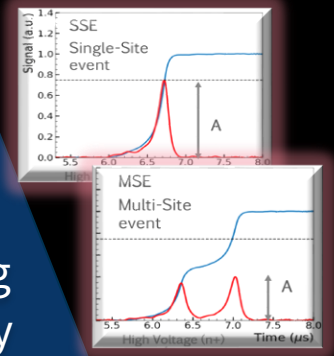
^{76}Se + 2e^{-}

Germanium detectors have many advantages that make them well suited for 0νββ decay searches

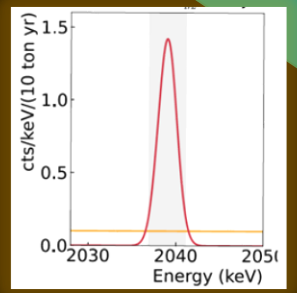
Well-established detector technology

Low intrinsic background

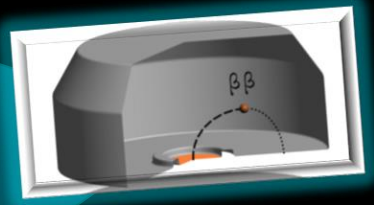
Background rejection using event topology

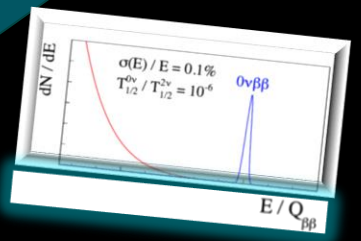


Sharp peak above flat, well-understood background

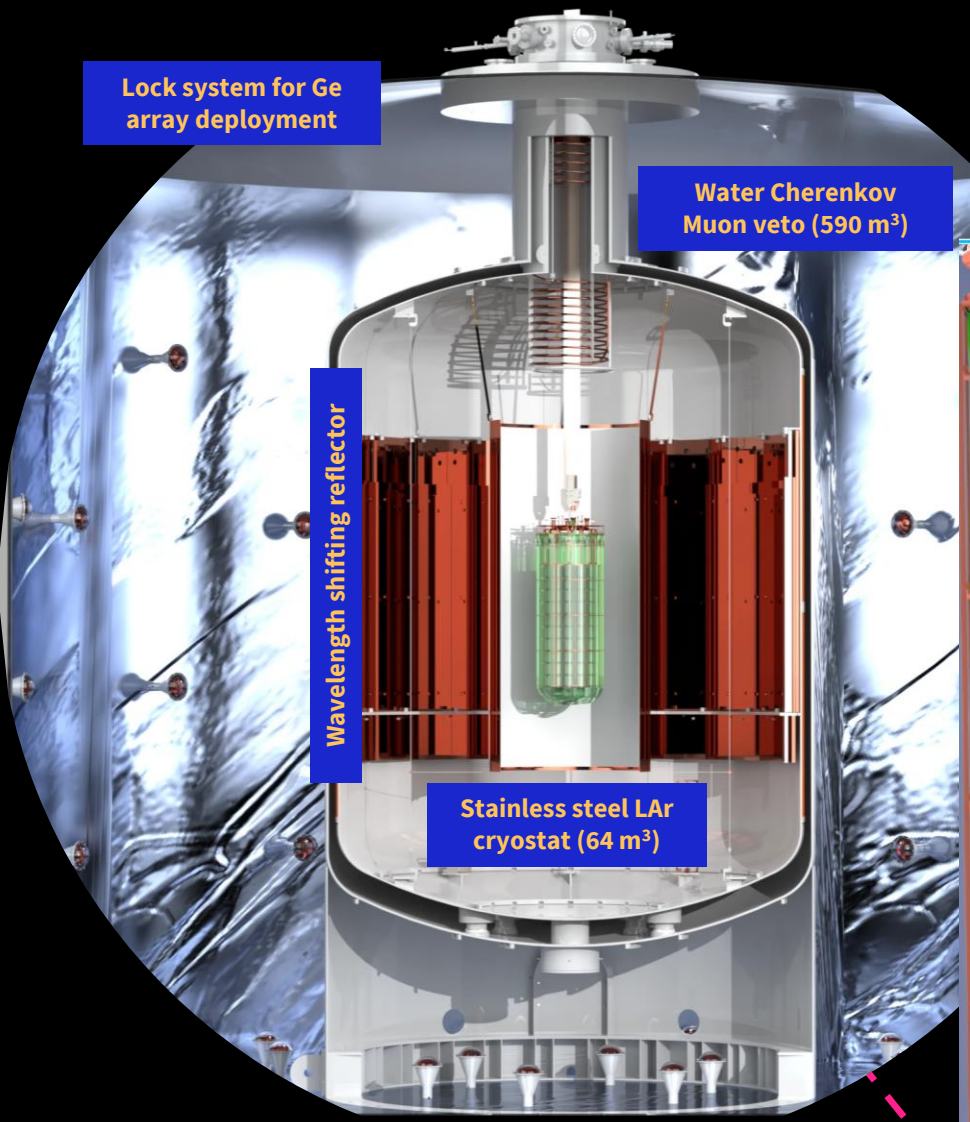


Source = detector, Energy resolution ~ 0.1% FWHM at $Q_{\beta\beta}$





The LEGEND - 200 experiment



HPGe readout electronics based on MJD Low Mass Front-end And GERDA charge sensitive amplifier (CC4)

Detector mount: underground copper, Optically active PEN plates & radiopure PEN

Scintillating, self-vetoing

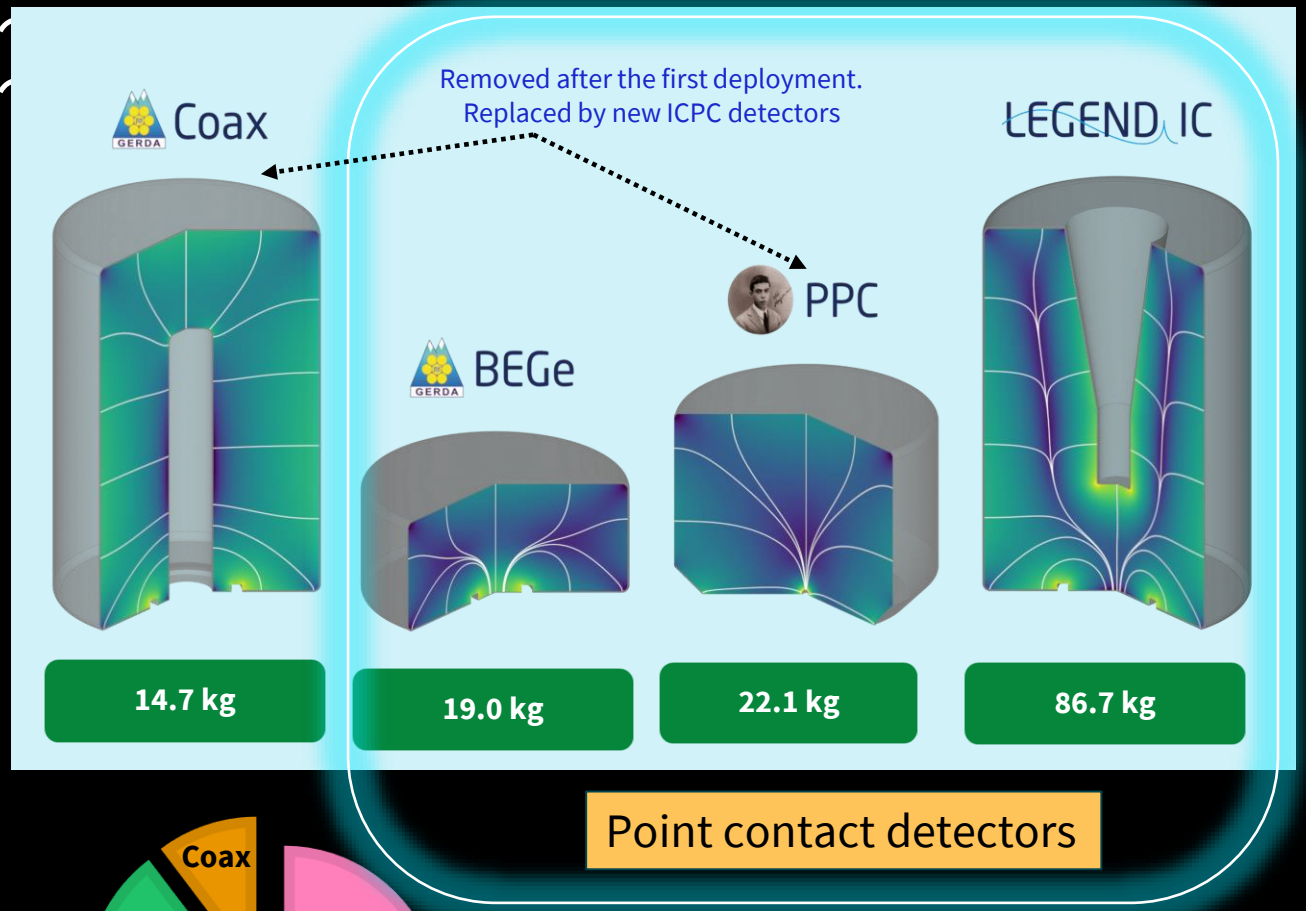
Liquid Argon instrumentation: Inner & outer fiber barrels with silicon photomultiplier (SiPM) readout at the top & bottom

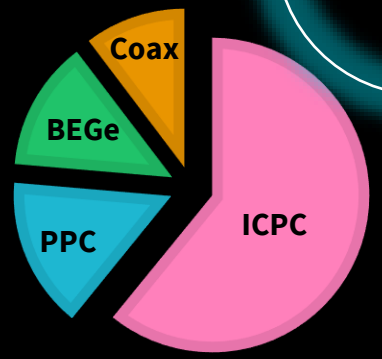
Larger mass (inverted coaxial) HPGe detectors up to 4 kg

Source funnels for calibration sources

Illustration by Michael Willers

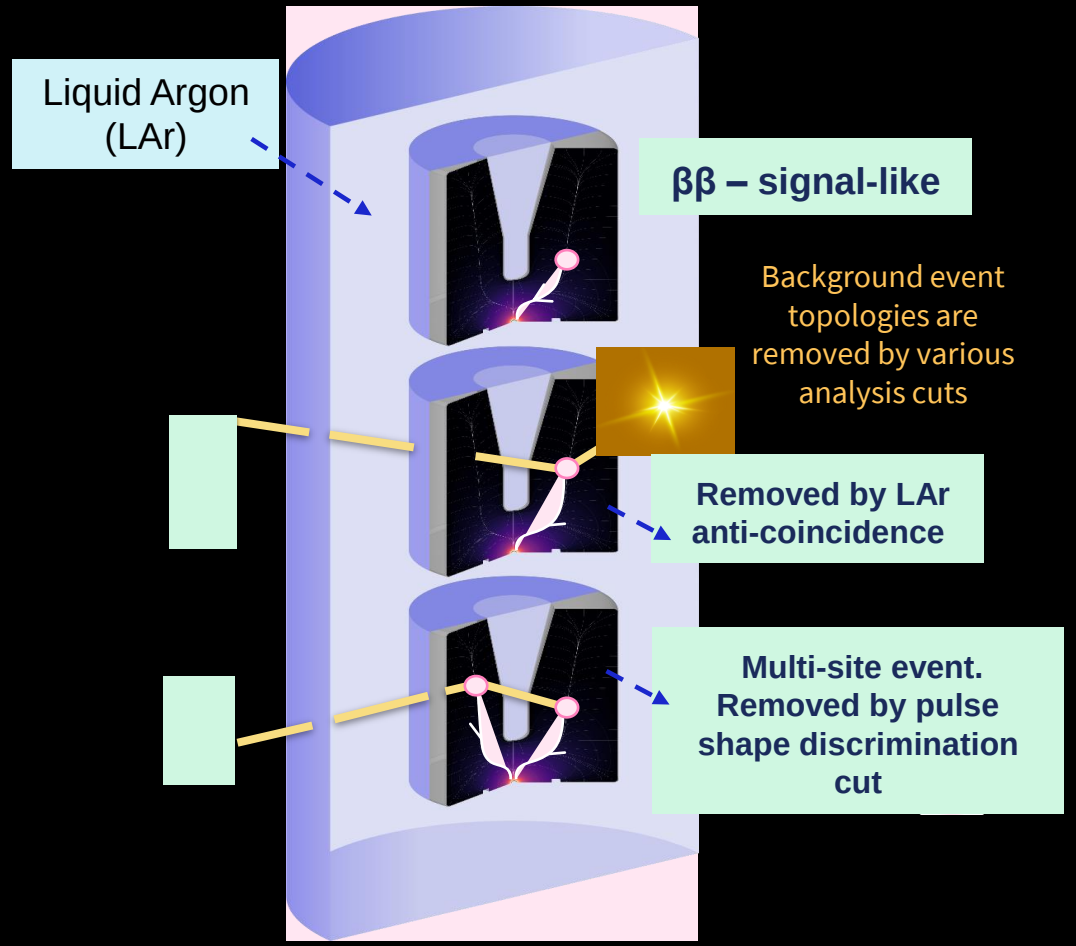
The LEGEND-200 detectors include the detectors from the past experiments and new ICPC detectors



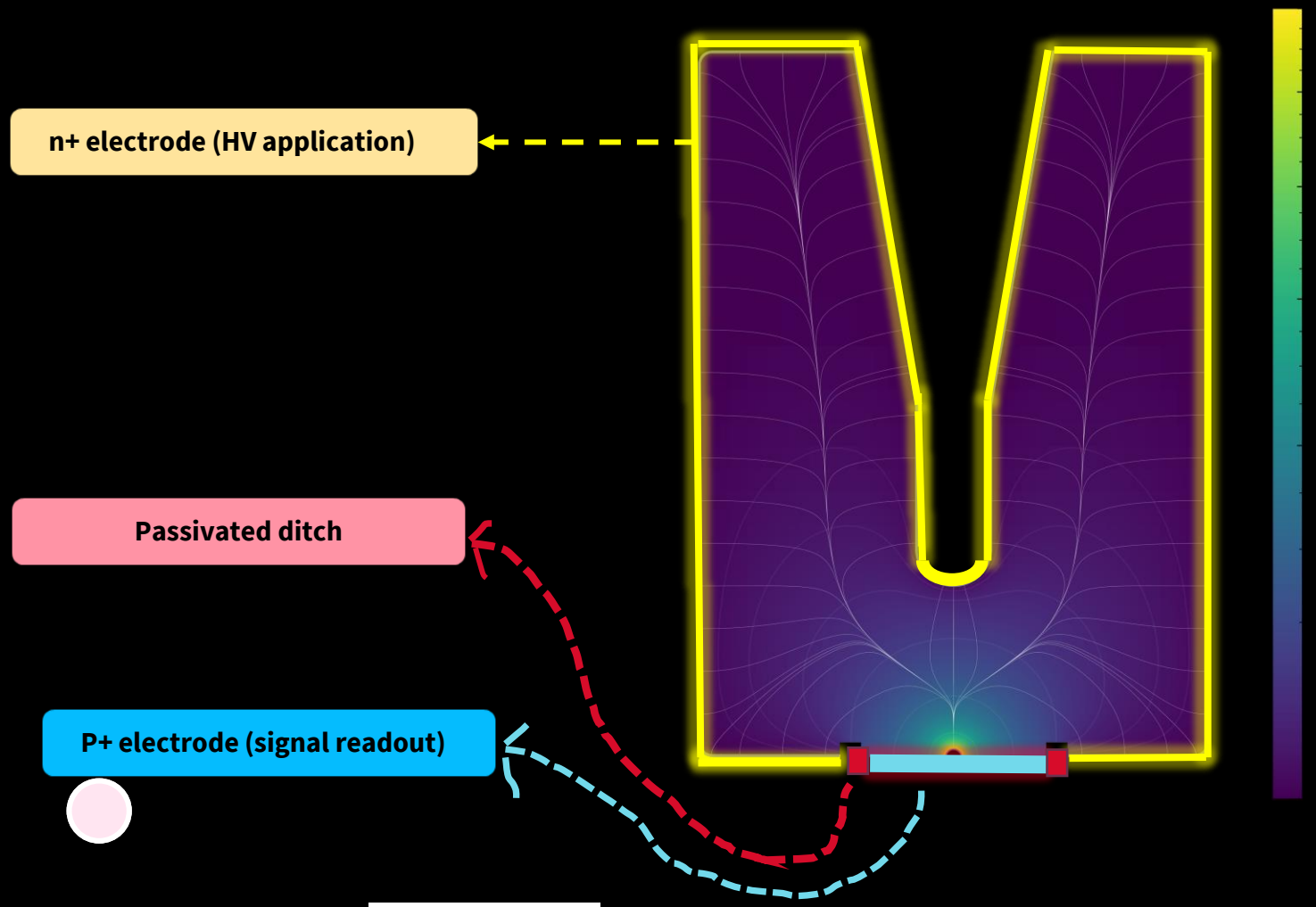


Total Ge detector mass: ~142 kg

Detector composition by mass in the first LEGEND-200 deployment

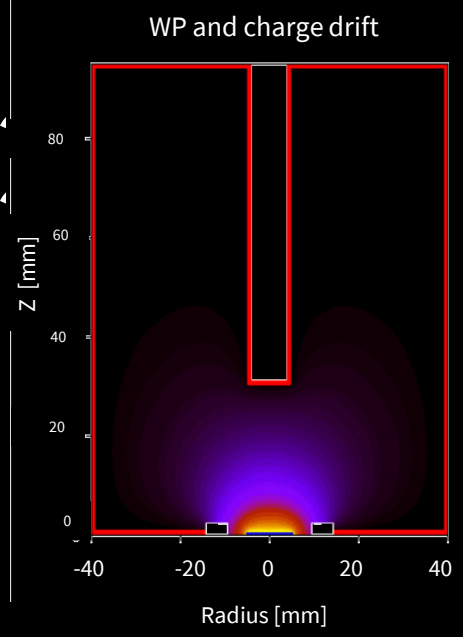


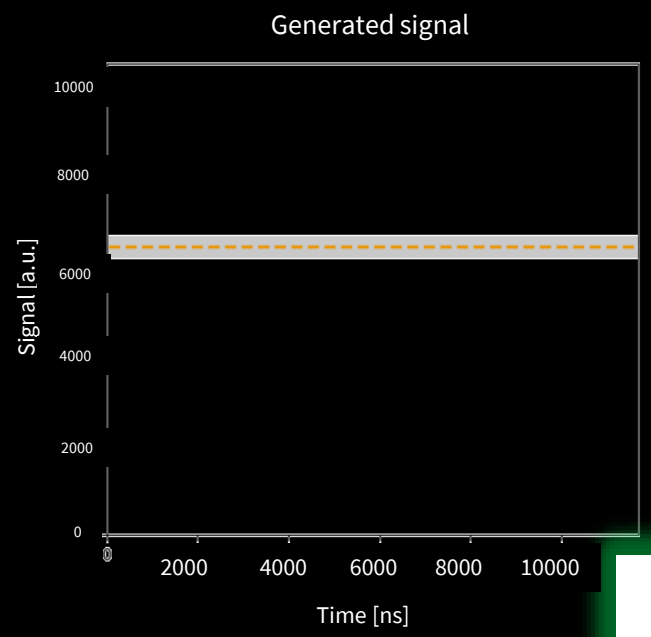
The point contact detector geometry plays a crucial role in Pulse Shape Discrimination (PSD)



Largely uniform electric field.
Strongly increases in the close vicinity of the point contact

- Similar waveforms in large part of the volume
- Surface events: faster pulses close to p+ and slower near n+
- Multi-site events: can be treated as superposition of single interactions



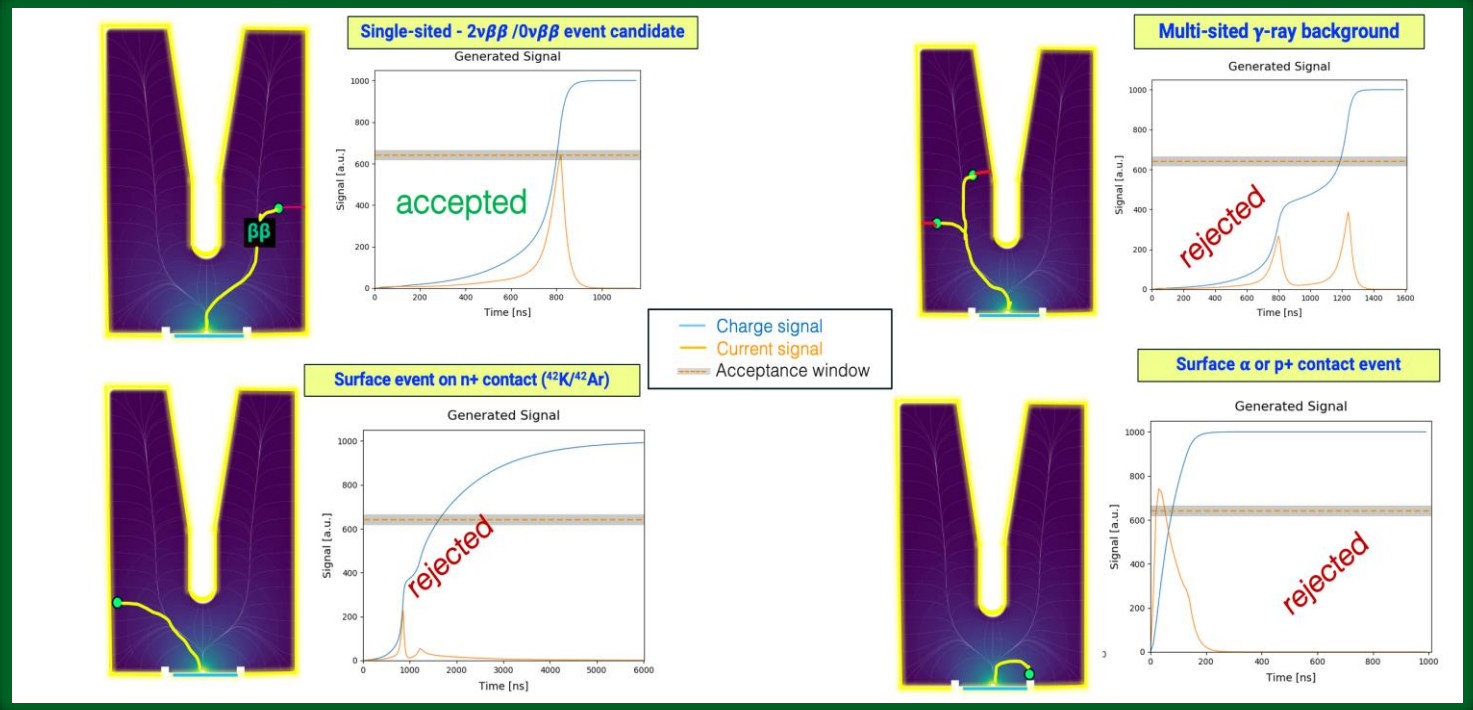


----- Charge signal
----- Current signal
Acceptance window

Current is smoothed derivative of the waveform

Rejection of multi-site and surface events with A/E classifier.

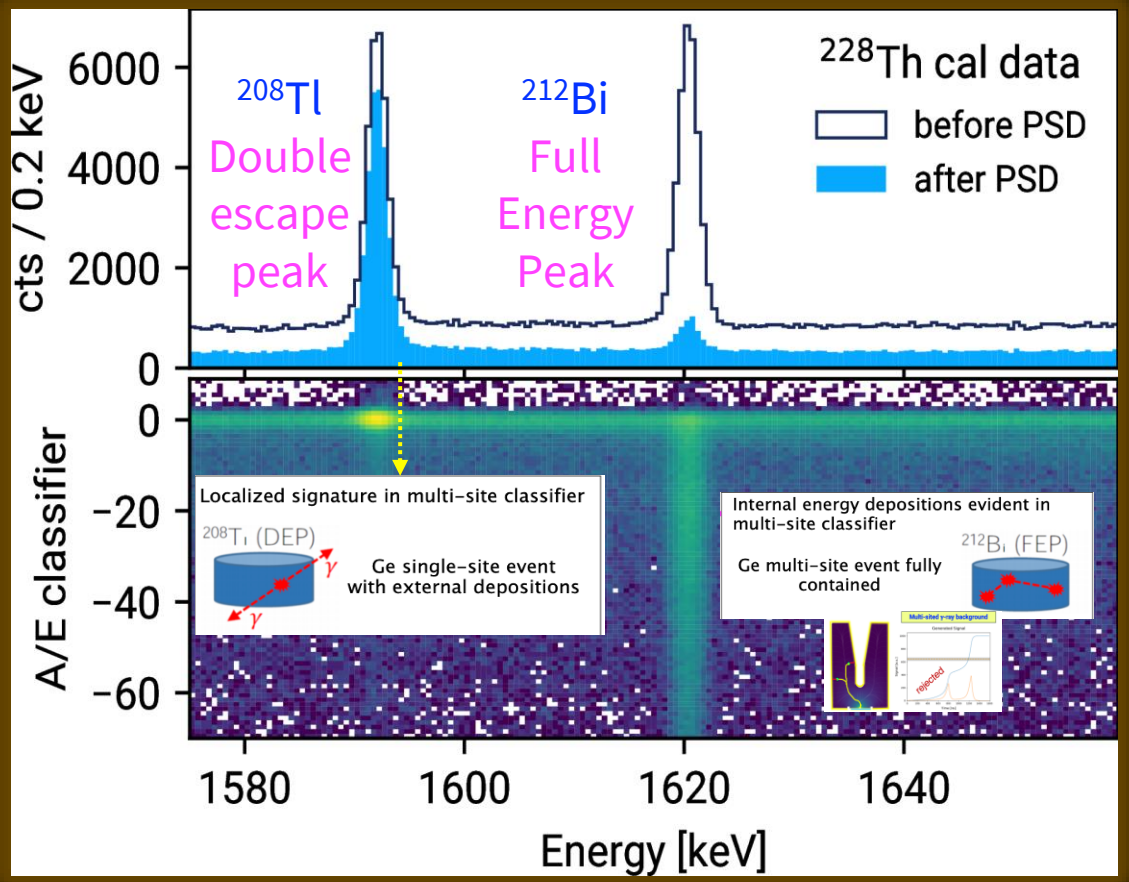
A/E = (current)Amplitude/Energy



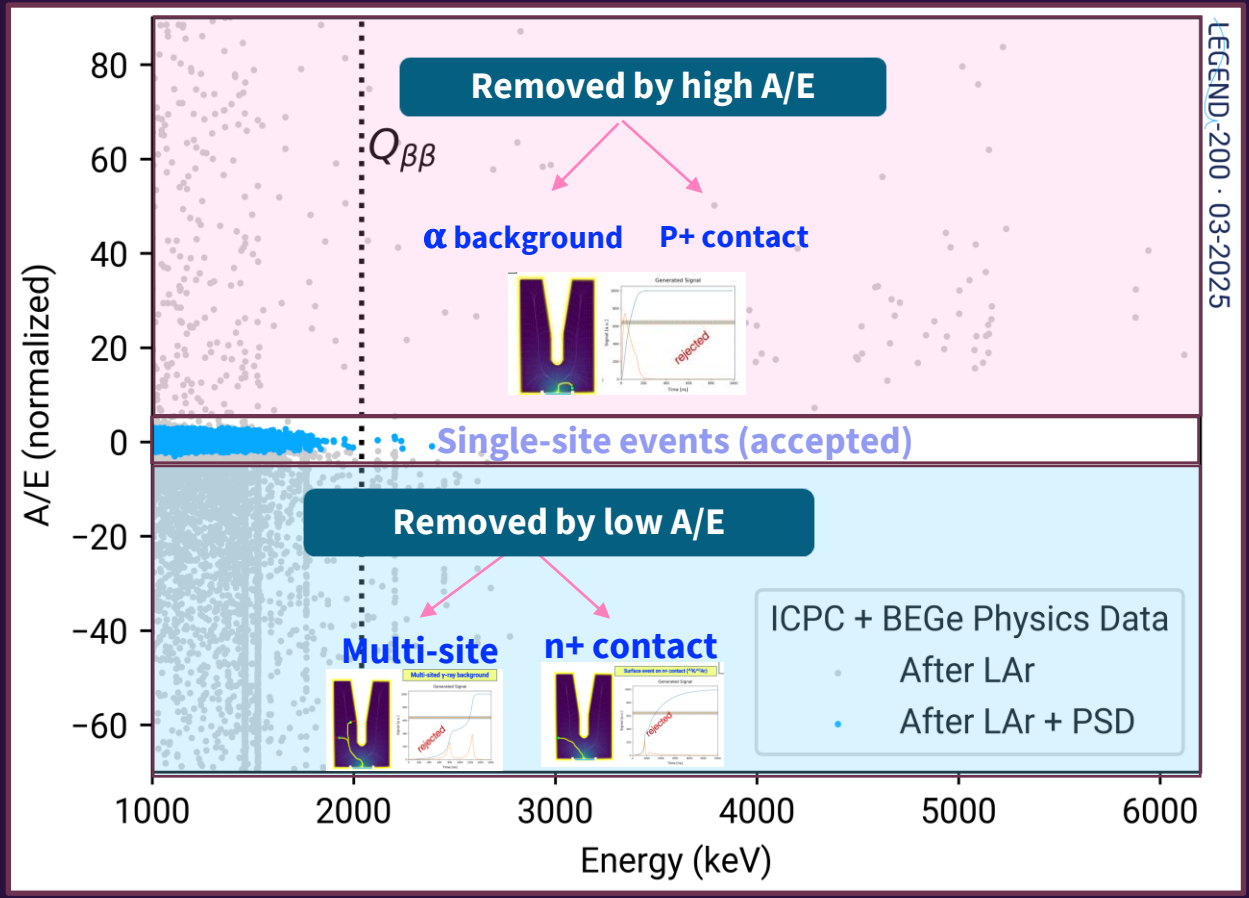
Rejection of multi-site and surface events with A/E classifier

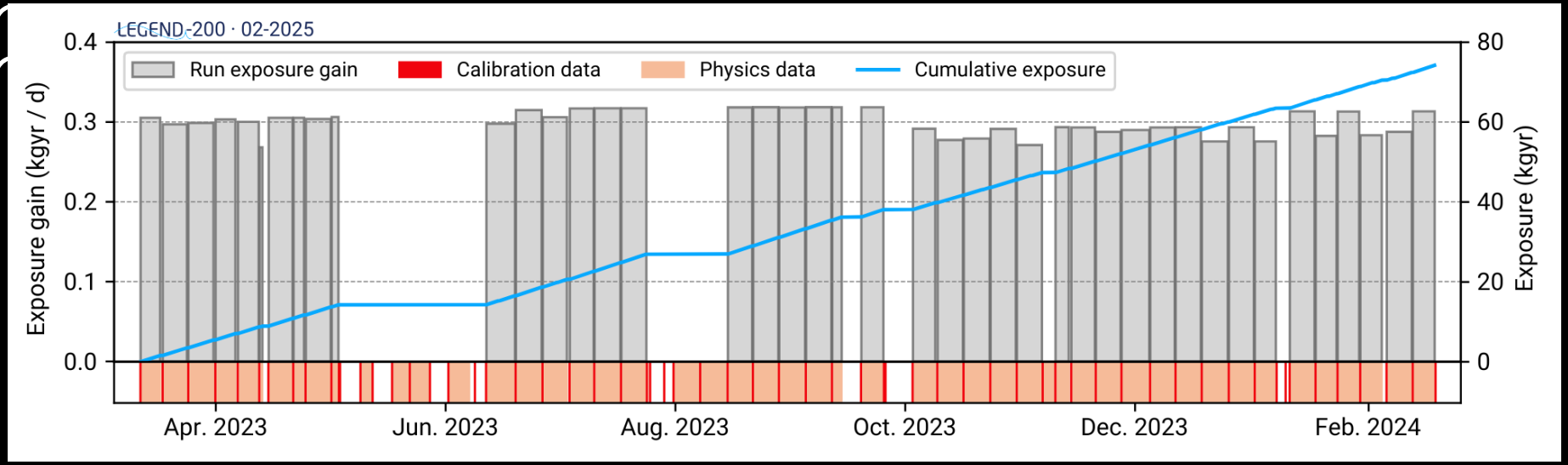
A/E = (current)Amplitude/Energy

Calibration data

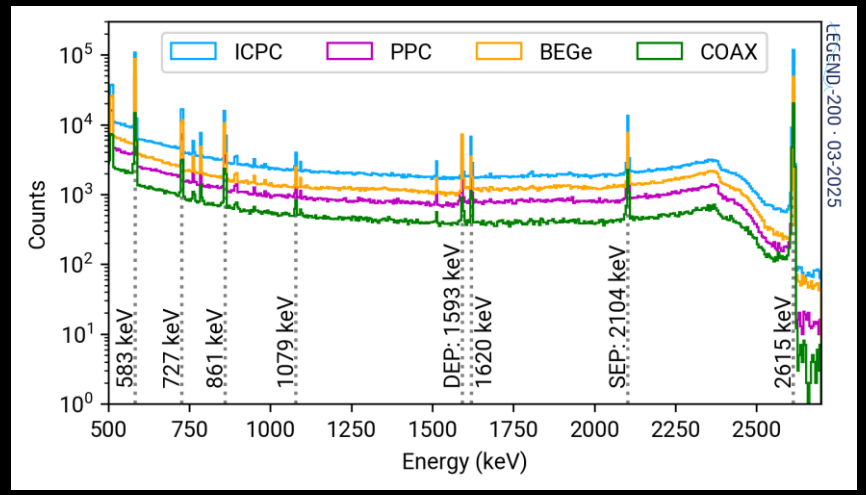


Background data

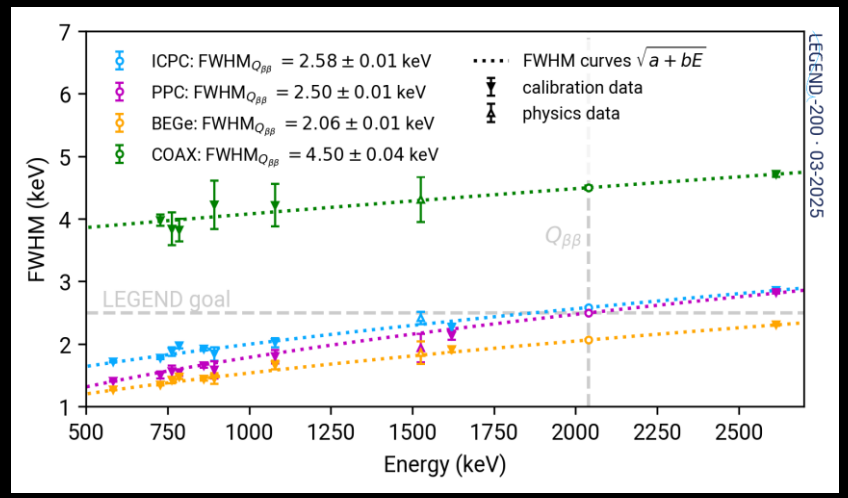




Summary of the Cumulative data from March 2023: 61 kg.yr of exposure



HPGe detector spectra

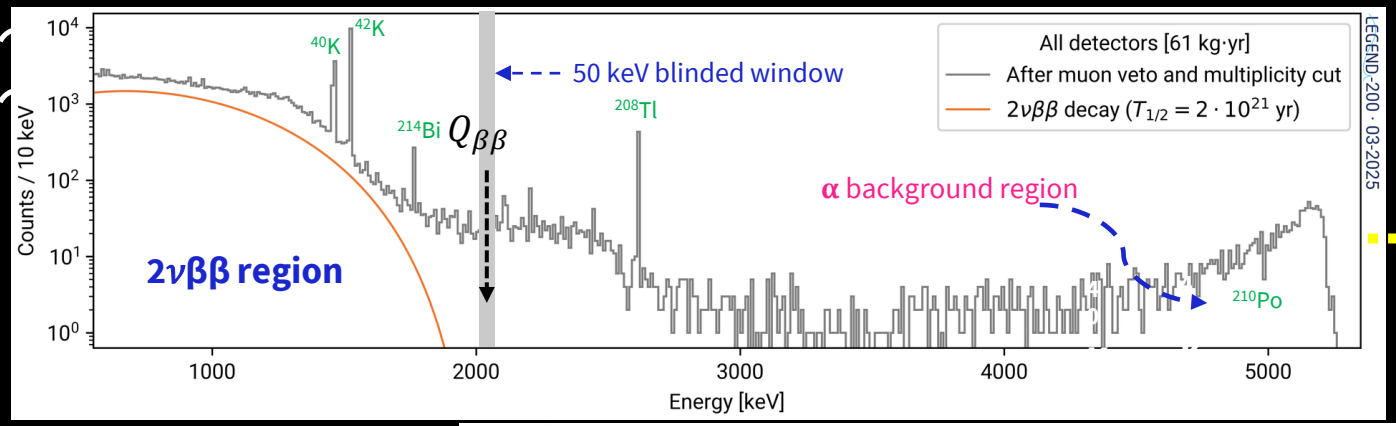


HPGe detector resolution

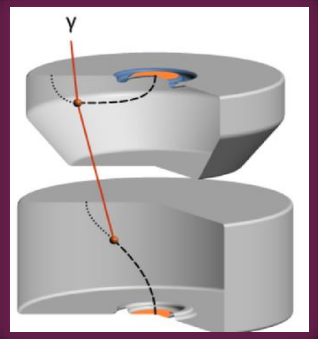
LEGEND-200 had stable energy observables over the first year of data-taking

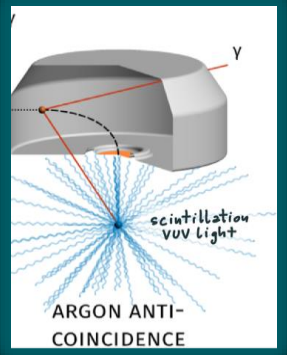
The stability is monitored with ^{228}Th weekly calibration data

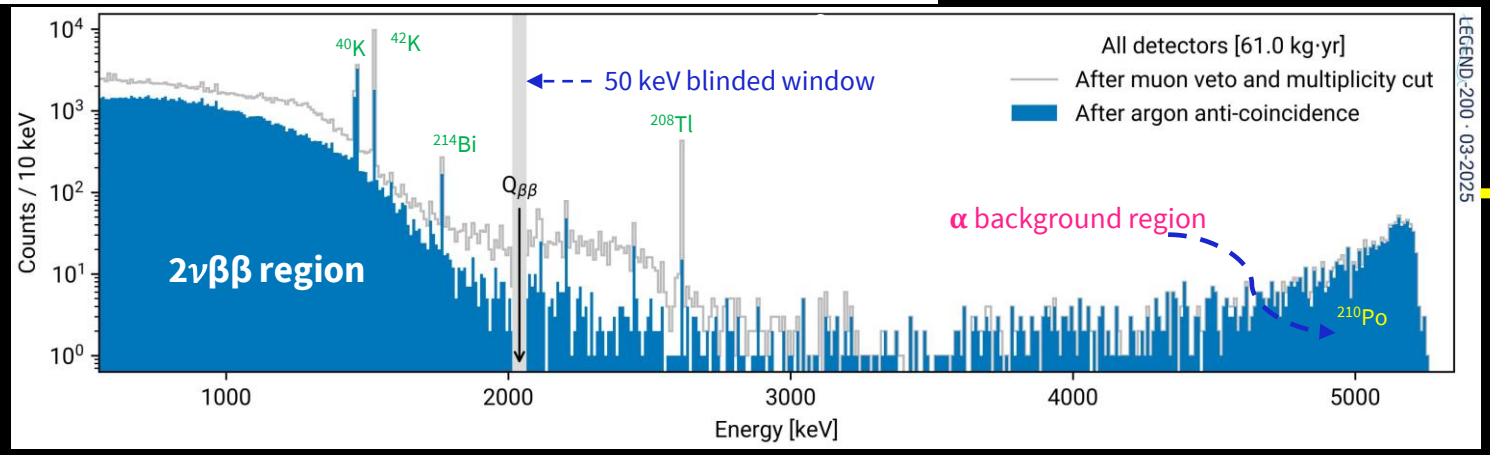
~0.1% FWHM at $Q_{\beta\beta}$



LEGEND-200 HPGe detector spectrum corresponding to 61 kg.yr of exposure. Data-cleaning, muon veto and multiplicity cuts applied.

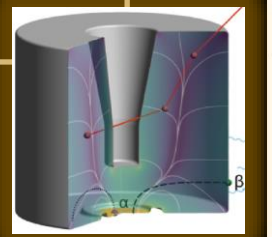


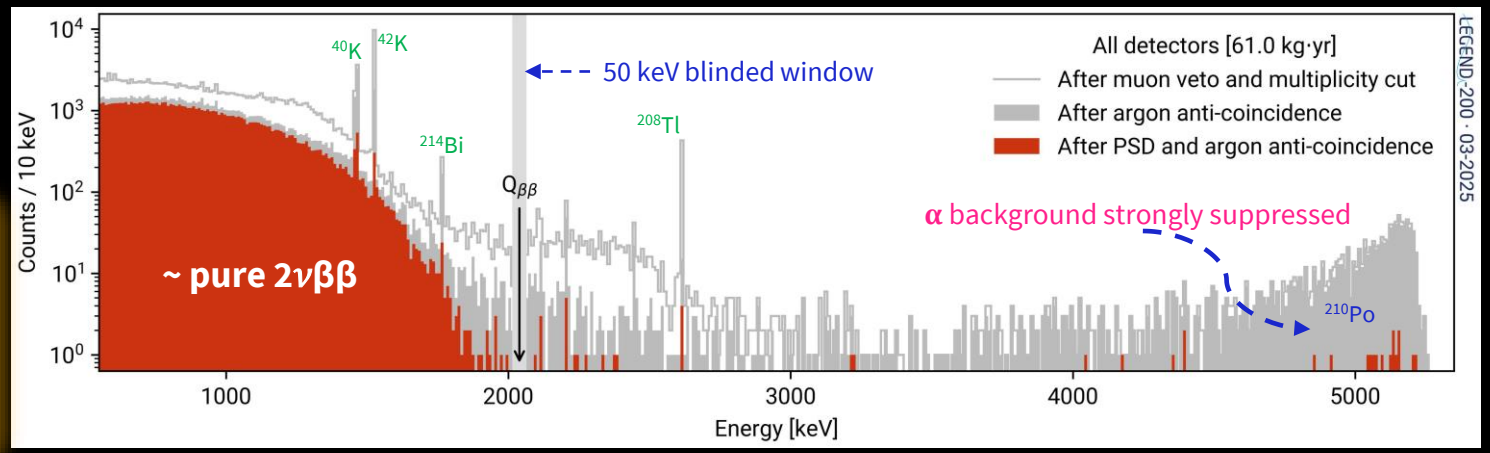




After the application of LAr Veto (blue filled) to the above spectrum. Background above 2νββ strongly suppressed. ~93% signal acceptance

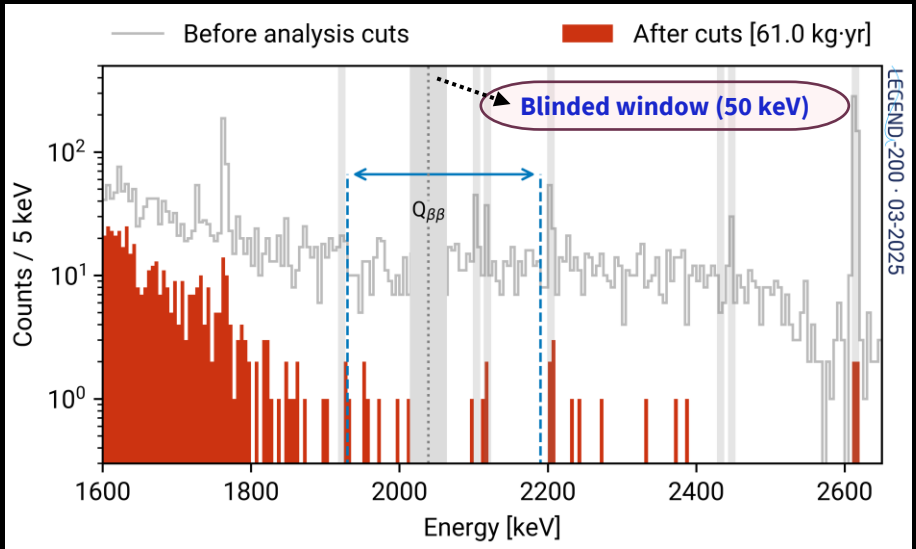
The spectrum after applying data cleaning PSD, and LAr anti-coincidence (red filled). Strong suppression of backgrounds. 0νββ survival fraction of ~60%



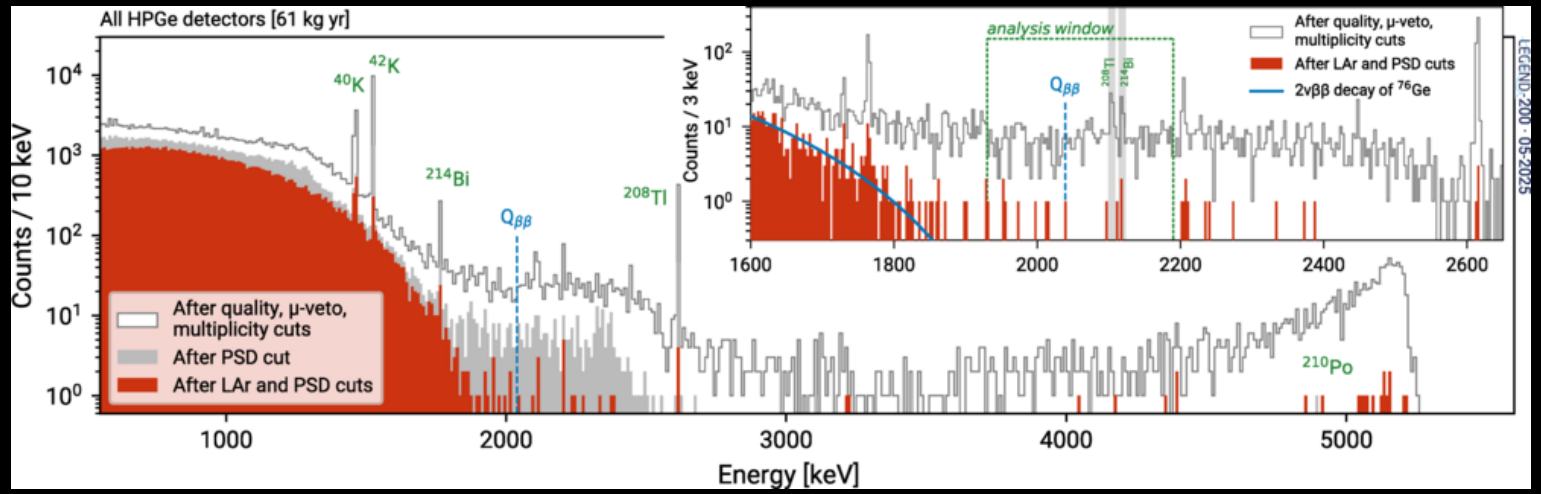


Prior to unblinding

After the analysis cuts, 9 events survive in the Background estimation window (1930 to 2190 keV)



Unblinded!



Only 2 additional events after unblinding

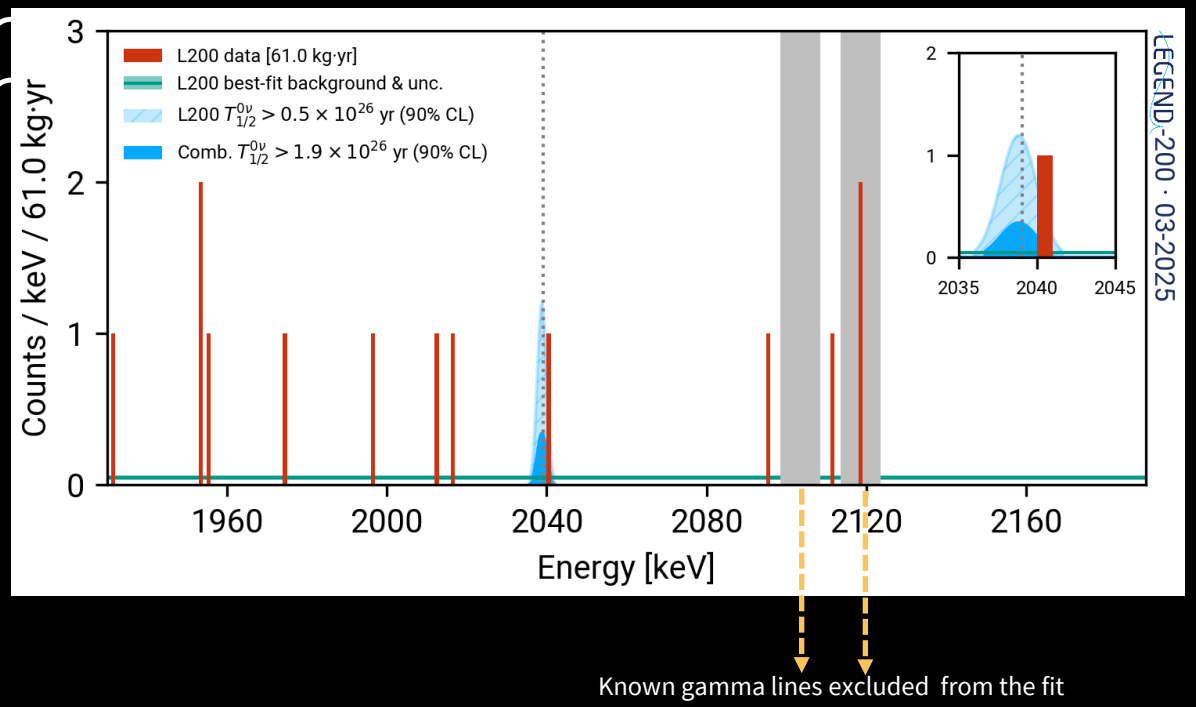
Background indices:

BI_{gold} [48 kg.yr]: $5.4^{+2.7}_{-2.0} \times 10^{-4}$ cts/(keV.kg.yr)

World leading among 0νββ experiments, Comparable to GERDA

BI_{silver} [13 kg.yr]: $13^{+8.0}_{-5.4} \times 10^{-4}$ cts/(keV.kg.yr)

Primarily coaxial detectors with seemingly worse background rejection



Known gamma lines excluded from the fit

$T_{1/2}$ ($0\nu\beta\beta$) lower limits (90% frequentist C.L.)
(combined fit from GERDA, MAJORANA and LEGEND)
(252.7 kg.yr)

Half life: $T_{1/2}$ ($0\nu\beta\beta$) >1.9 x 10^{26} yr
Median sensitivity: 2.8 x 10^{26} yr (world-leading)

$m_{\beta\beta}$ < 75 -200 meV

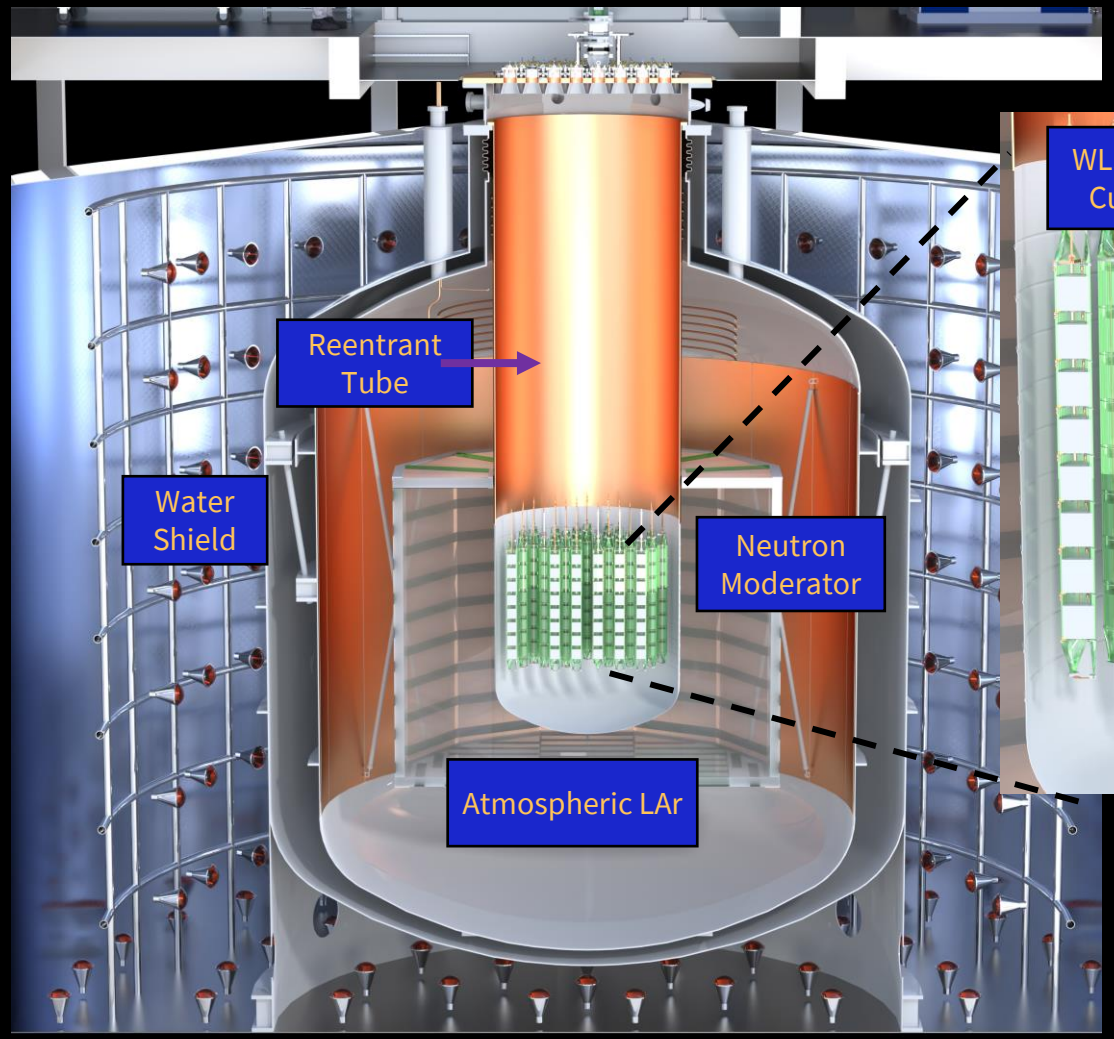
One event at 1.4σ from $Q_{\beta\beta}$ weakens combined limit

(background-only p-value = 0.1, does not reach 3σ significance for discovery)

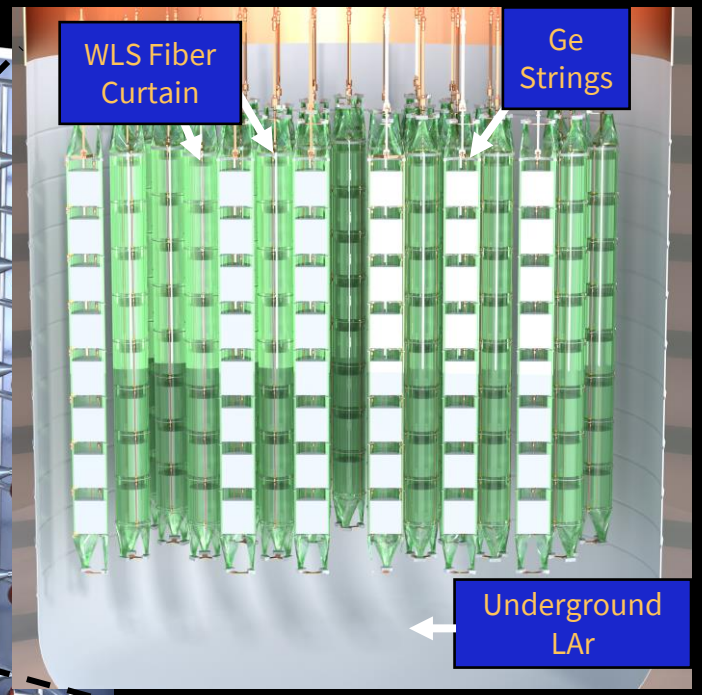
After maintenance and background characterization, detectors have been recommissioned.

LEGEND-200 is presently taking data from the second physics deployment with new additional ICPC detectors.

Towards Ton-scale: LEGEND - 1000



336 detectors distributed among 42 strings

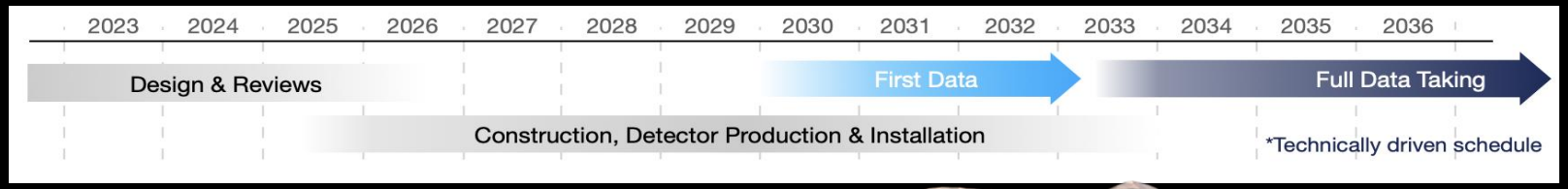


Underground-sourced Argon (UGLAr) to mitigate the ^{42}Ar background

Radiopure electronics and cables

Large-mass (3 kg) high purity p-type ICPC detectors
Enriched to more than 90% in ^{76}Ge

LEGEND-1000 is optimized for a quasi-background-free 0νββ search fully covers the inverted neutrino masses



Low backgrounds, excellent resolution, and event topology discrimination allow for an unambiguous discovery of 0νββ decay at $T_{1/2} = 10^{28}$ years

THANK YOU

Questions?

https://legend-exp.org/

H. Acharya et al., PRL 136, 022701 (2026)

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First Results on the Search for Lepton Number Violating Neutrinoless Double-β Decay with the LEGEND-200 Experiment

H. Acharya[1,2], N. Ackermann[3], M. Agostini[4], A. Alexander[4], C. Andreoiu[5], G. R. Araujo[6], F. T. Avignone, III[7,8], M. Babicz[6], W. Bae[9] *et al.* (LEGEND Collaboration[¶])

Show more

Phys. Rev. Lett. **136**, 022701 – **Published 16 January, 2026**

DOI: https://doi.org/10.1103/25tk-nctn

^{76}Ge is a leading isotope for $0\nu\beta\beta$ searches, LEGEND will b commissioned two stages

LEGEND-200 completed its first $0\nu\beta\beta$ unblinding with 61 kg yr of exposure, results published in PRL

LEGEND-1000 is optimized for a quasi-background-free $0\nu\beta\beta$ search, has a low-risk path to meeting its background goal of 10^{-5} counts/(keV kg yr) with discovery sensitivity beyond 10^{28} years

LEGEND-200 achieved world-leading background level among $0\nu\beta\beta$ experiments, comparable to GERDA

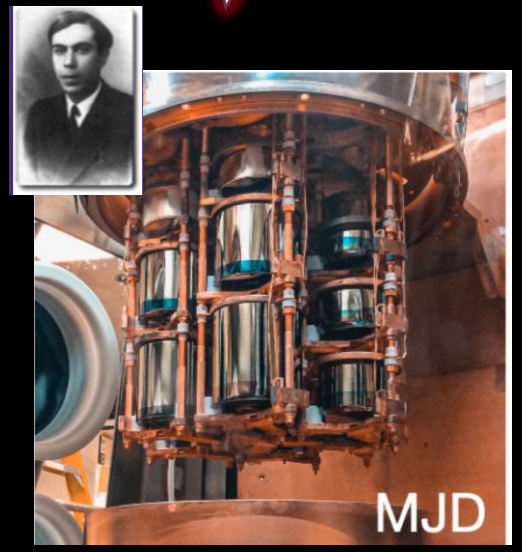
BACK UP SLIDES

LEGEND brings the innovation + expertise from its very successful, ^{76}Ge-based, predecessors

MAJORANA DEMONSTRATOR

Sanford Underground Research Facility (SURF) in Lead, SD

2015-2021



$T_{1/2}$ ($0\nu\beta\beta$) > 8.3 x 10^{25} y (90% C.L.)

64.5 kg yr

Achieved the best energy resolution 2.5 keV at 2039 keV

Phys. Rev. Lett. **130**, 062501 (2023)

THE GERMANIUM DETECTOR ARRAY

Laboratori Nazionali del Gran Sasso, INFN, Italy

2011-2020

$T_{1/2}$ ($0\nu\beta\beta$) > 1.8x10^{26} yr (90 % C.L.)

127.3 kg yr

Achieved the best background index 5 x 10^{-4} cts/(keV kg yr)

Demonstrated the operation of Ge detectors in liquid Argon For excellent background suppression

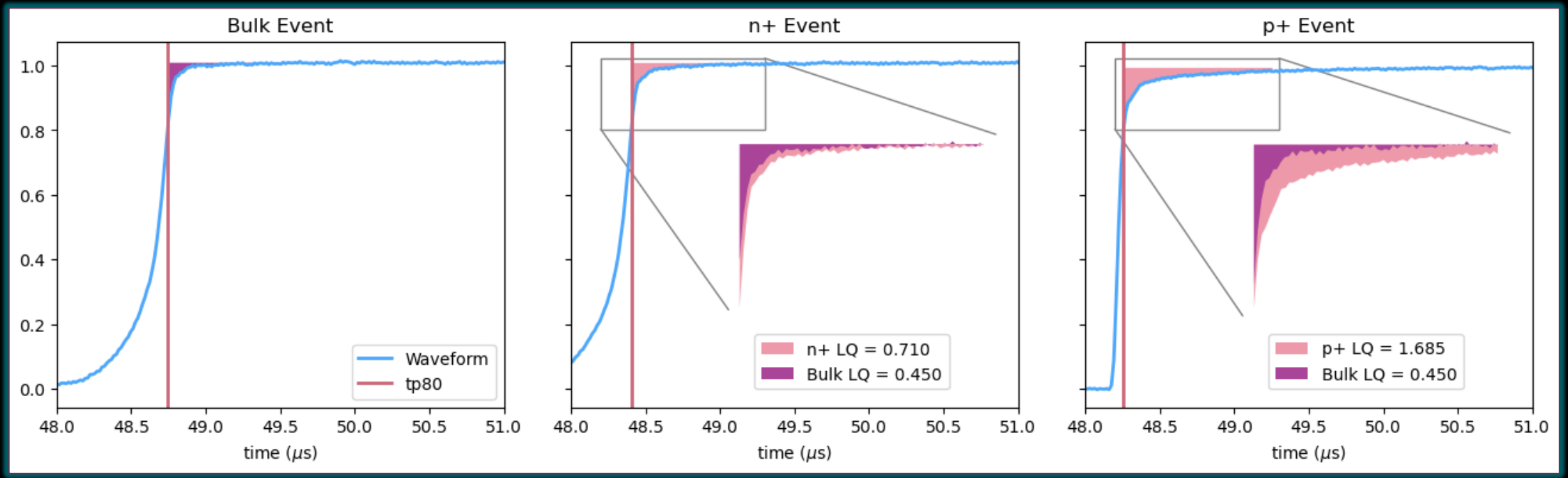
Phys. Rev. Lett. **125**, 252502 (2020)

Rejection of surface events with the Late Charge (LQ) classifier

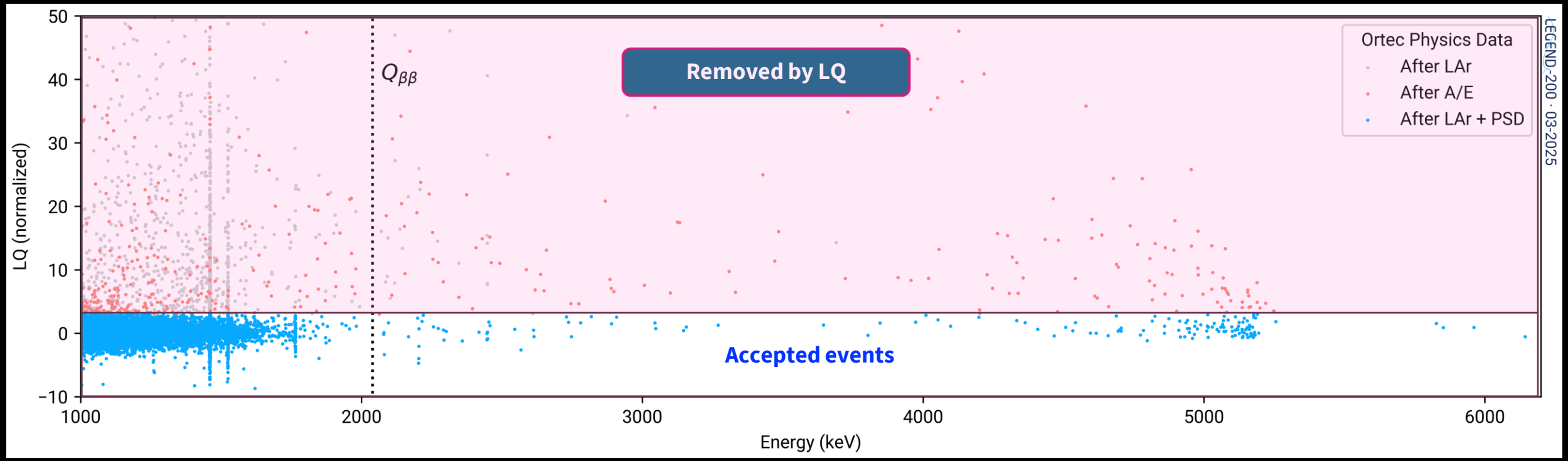
Passivated surface and n+ events exhibit slow charge rerelease

Quantified by the slow component above the rising edge after 80% of charge is collected – area above the waveform

These events are energy degraded - can contribute to the background

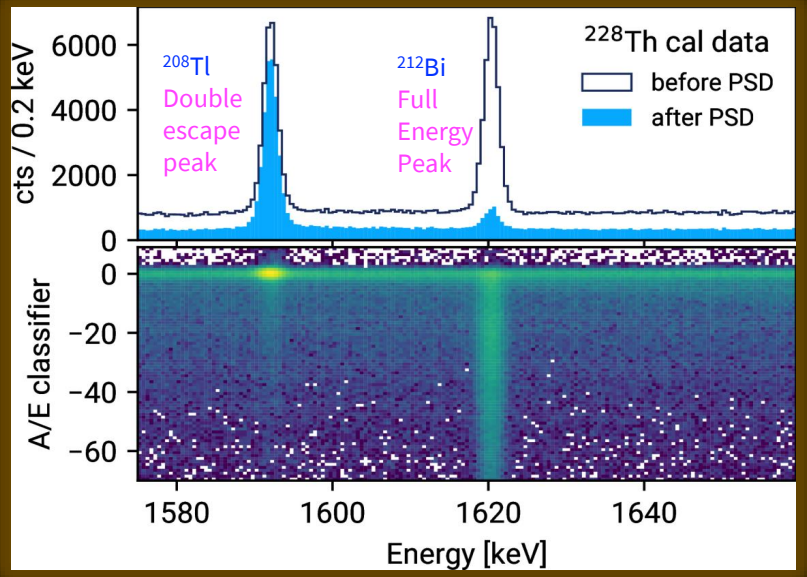


Rejection of surface events with the Late Charge (LQ) classifier



The PSD cuts are tuned using gamma lines from ^{228}Th source

Signal proxy – Double escape peak (**DEP**) from ^{208}Tl



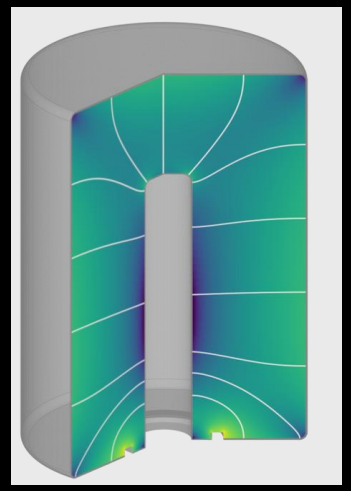
Low A/E cut set at 90% DEP acceptance

High A/E cut set at 3σ – > 96% DEP acceptance

LQ cut set at 3σ – > 98% DEP acceptance

Multi-site rejection is measured by Single escape peak (**SEP**), full energy peak (**FEP**) and **Compton continuum**

Artificial Neural network (ANN) is Used to discriminate single and Multi-site events for Coaxial detectors



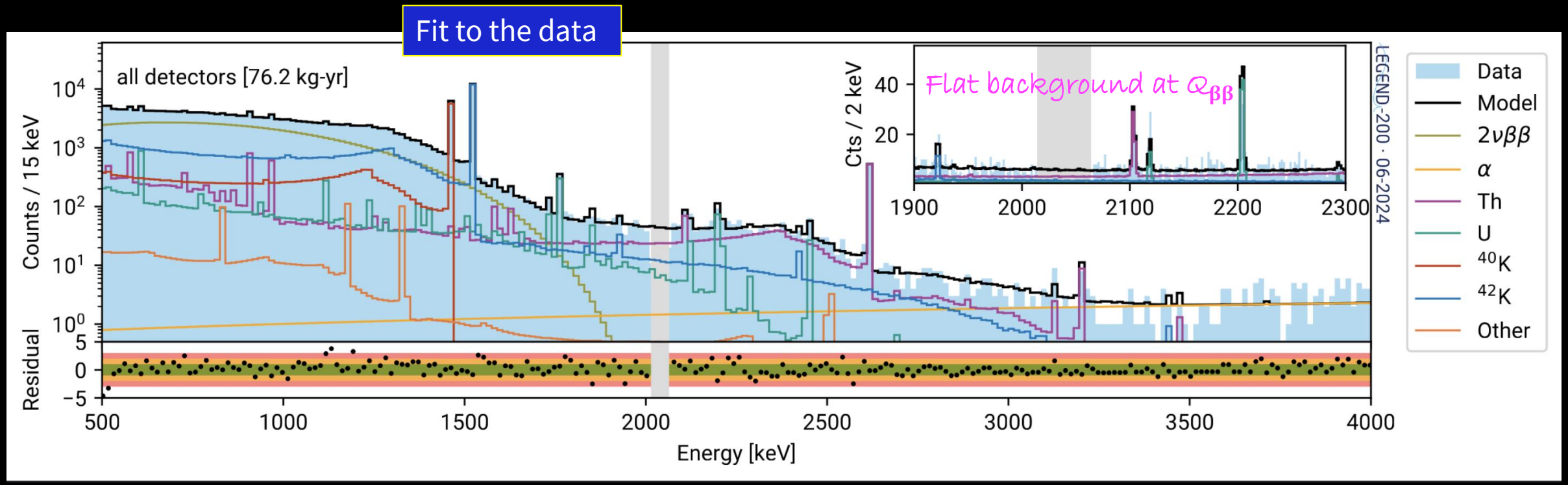
In the case of coaxial detectors, P+ contact events are rejected Using a cut based on the pulse Risetime. Similar method to GERDA ***Phys. J. C* 82, 284 (2022)**

Artificial Neural network (ANN) is Used to discriminate single and Multi-site events

PSD acceptances of LEGEND detectors with systematic errors

Det. Class	ϵ_{MSE}	ϵ_{surf}	ϵ_{PSD}	Exp. (kg-y)
ICPC	$89.79 \pm 1.03\%$	$98.60 \pm 0.28\%$	$84.85 \pm 2.96\%$	32.48
BEGe	$89.57 \pm 0.59\%$	$96.92 \pm 0.29\%$	$81.07 \pm 3.87\%$	10.87
PPC	$89.73 \pm 0.79\%$	$98.66 \pm 0.27\%$	$85.00 \pm 4.49\%$	4.90
Batch5	$90.51 \pm 1.10\%$	$93.06 \pm 0.48\%$	$80.55 \pm 3.09\%$	4.97
Coax	$76.00 \pm 2.10\%$	N.A.	$76.00 \pm 5.68\%$	7.76

The LEGEND-200 background model reproduces the data well, the model is flat at $Q_{\beta\beta}$



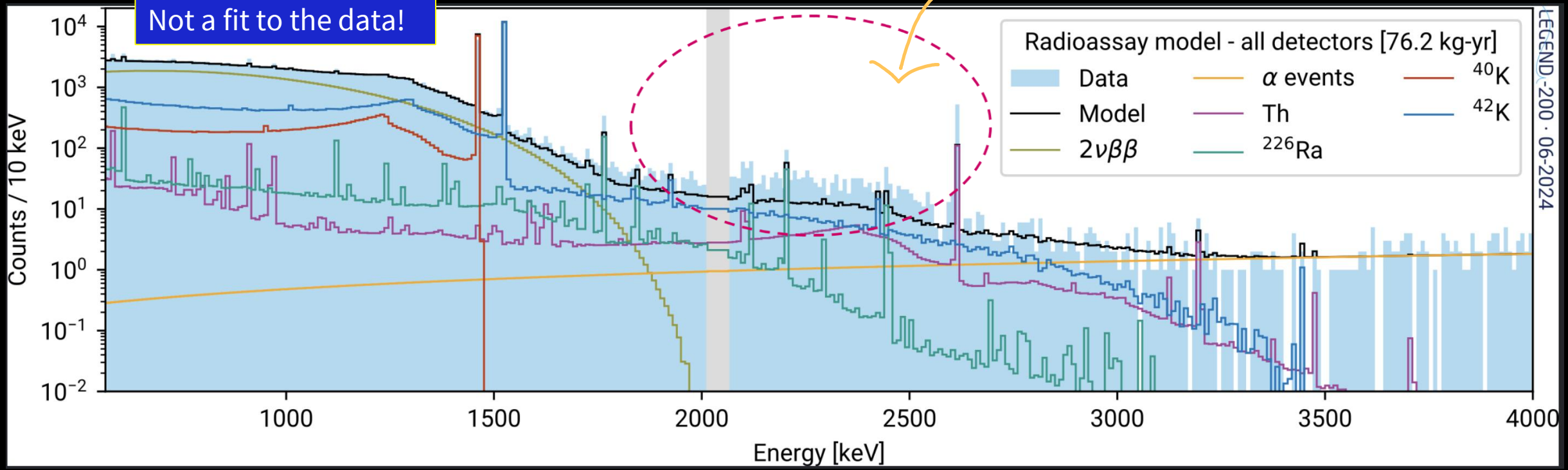
Simulations and material radioassay underpredict ^{228}Th in physics data (before analysis cuts)

Background excess identified (holder assembly, fibers).
Significant reduction of ^{214}Bi and ^{208}Tl lines
after re-cleaning and installation

Hard to estimate systematic uncertainty
on the assay results

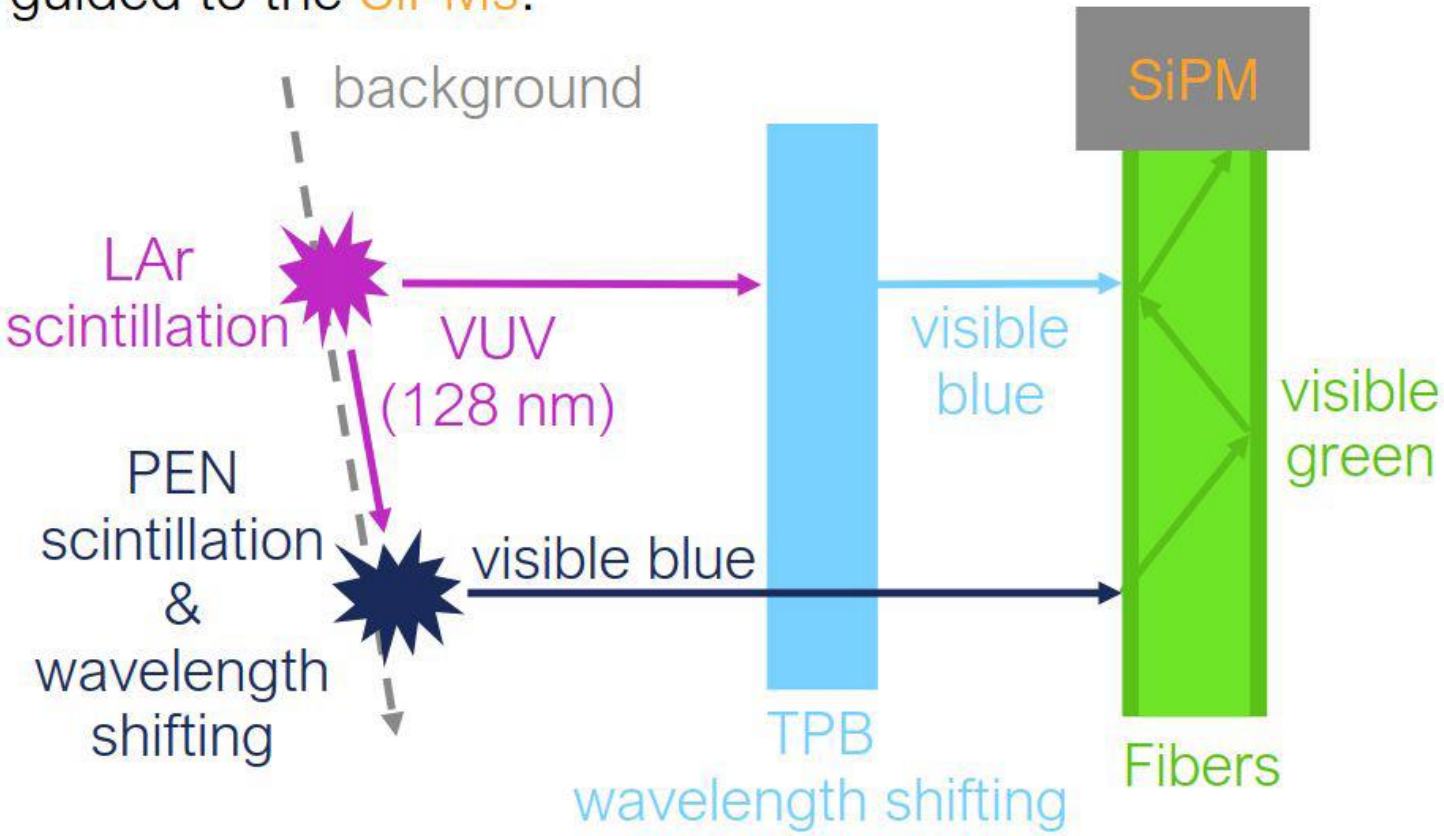
Background excess compared to assay
expectations

Not a fit to the data!

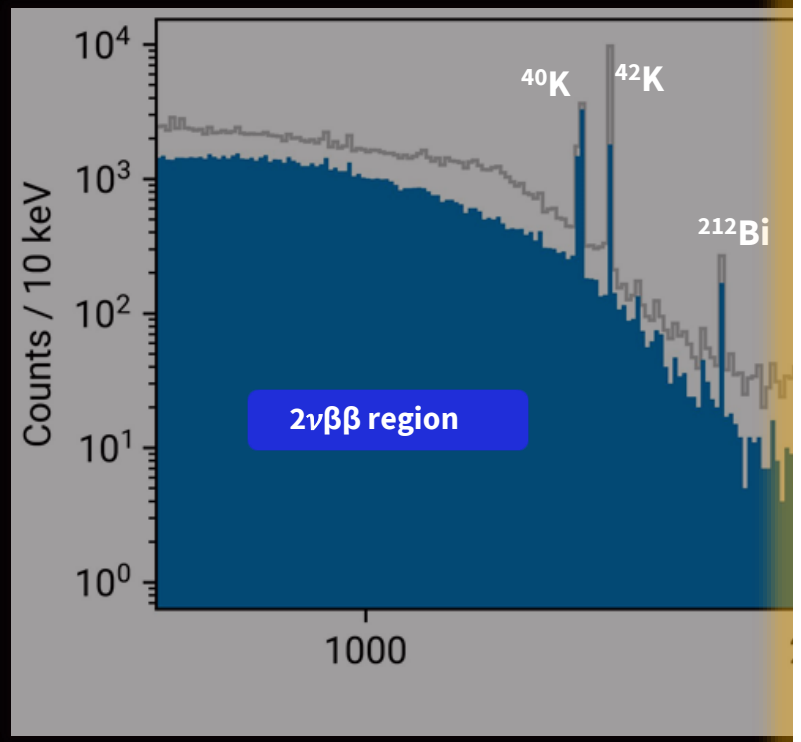


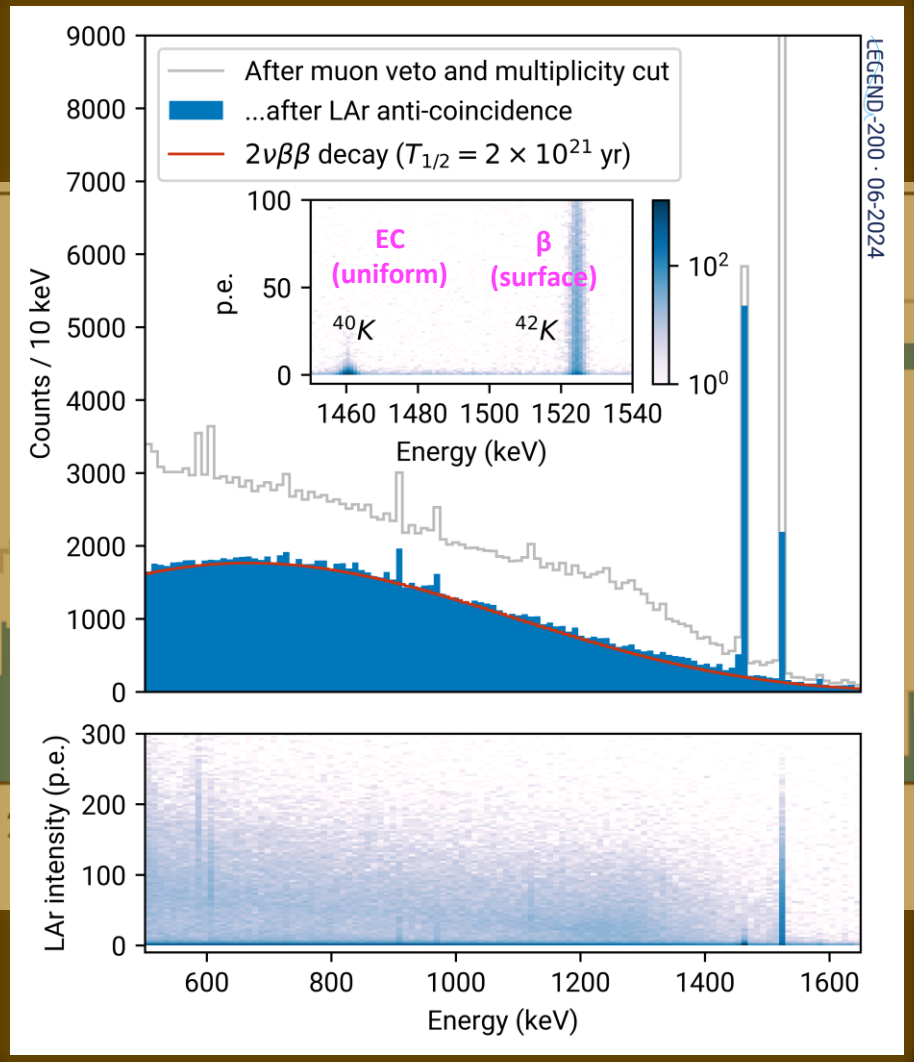
The LAr scintillation light (128 nm) is shifted to the visible blue by TPB (coating on fibers & WLSR) and PEN (detector holder plates).

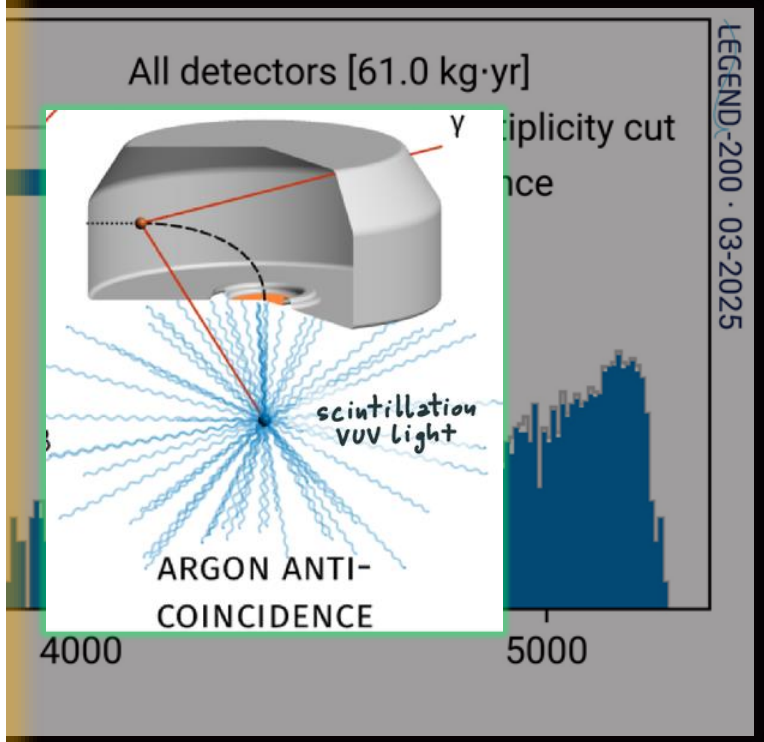
The blue light is shifted to visible green by the fibers and guided to the SiPMs.

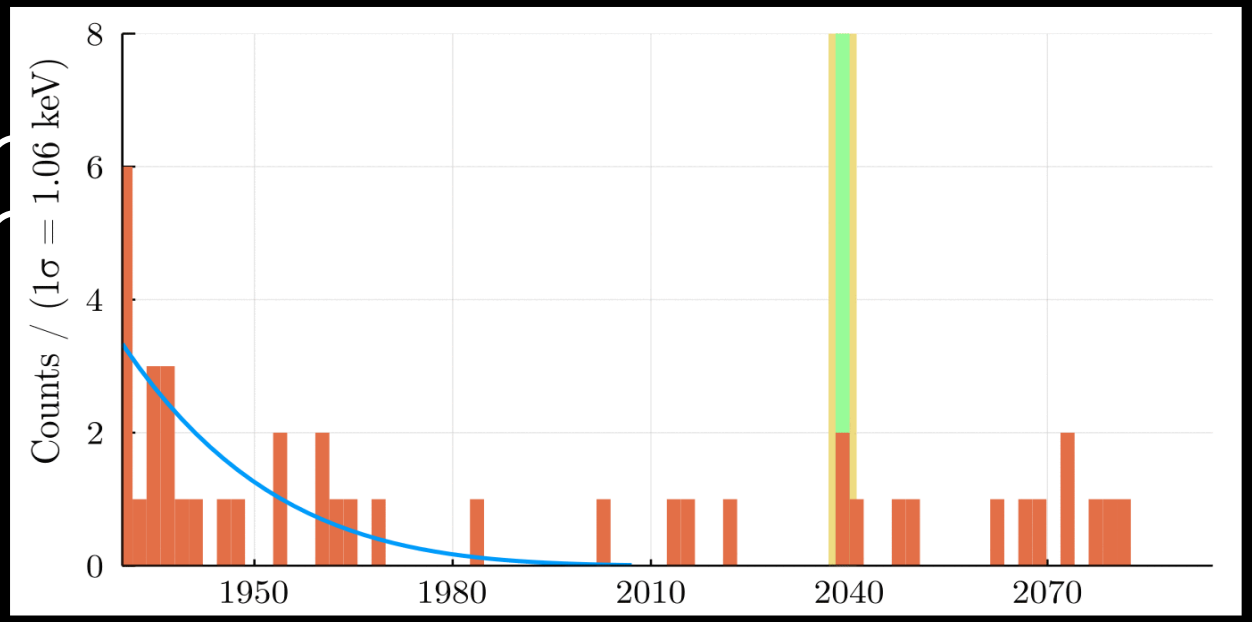


Background from the beta decay of ^{42}K is strongly suppressed after LAr anti-coincidence



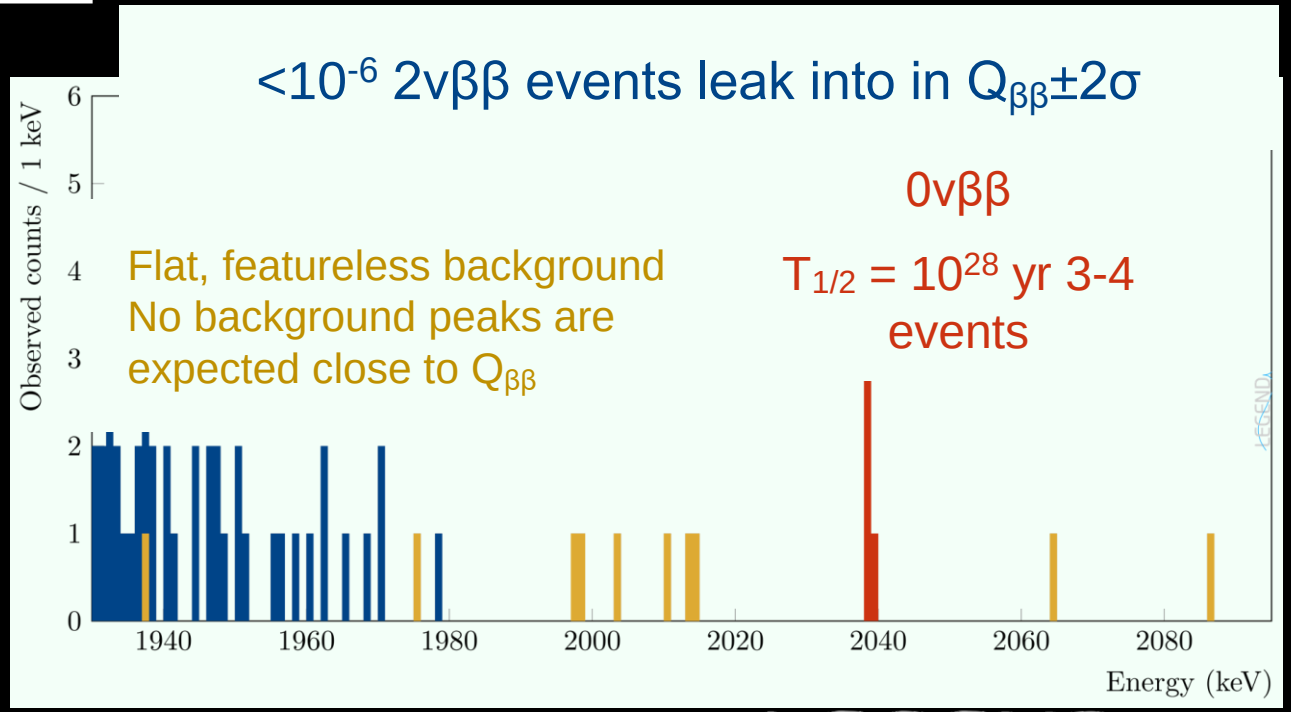
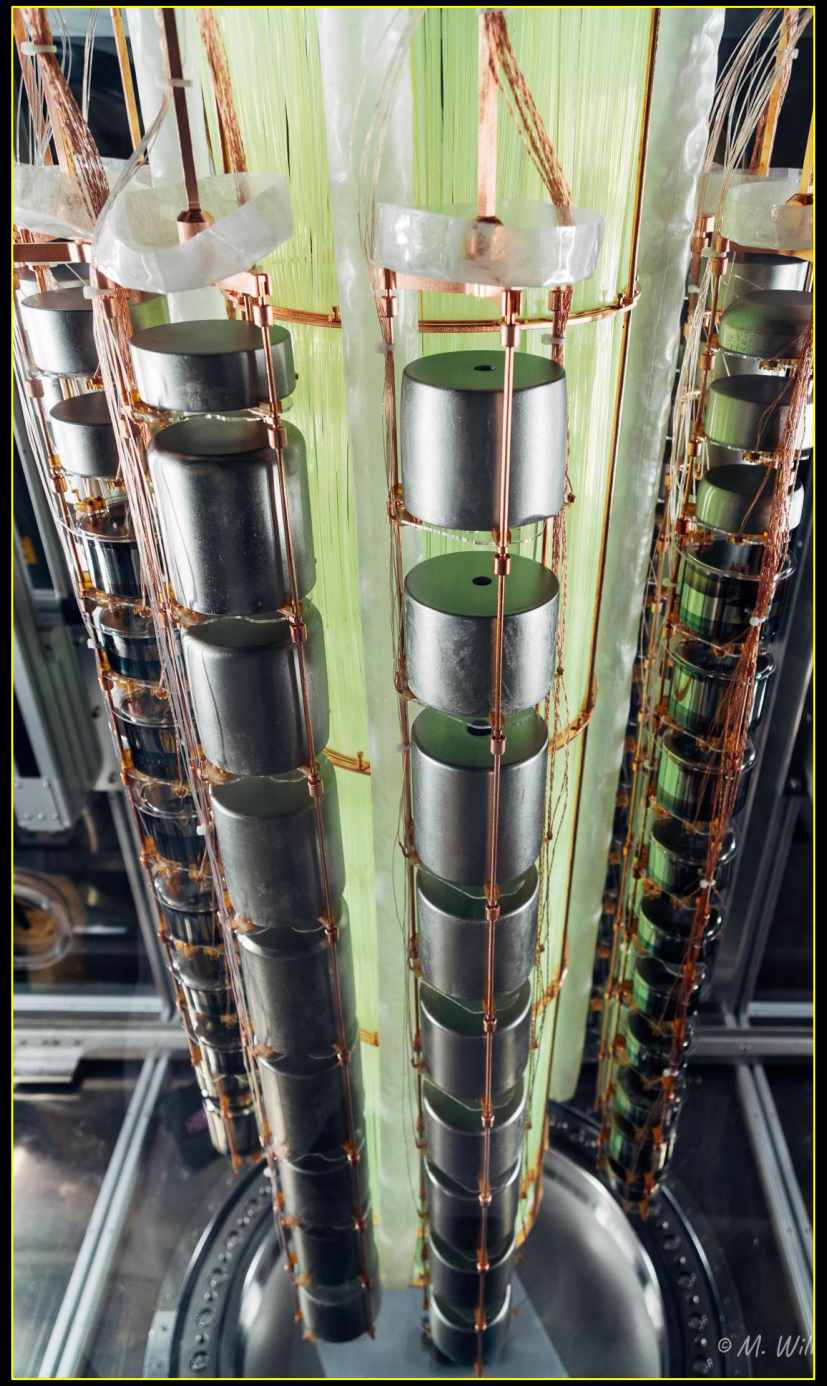
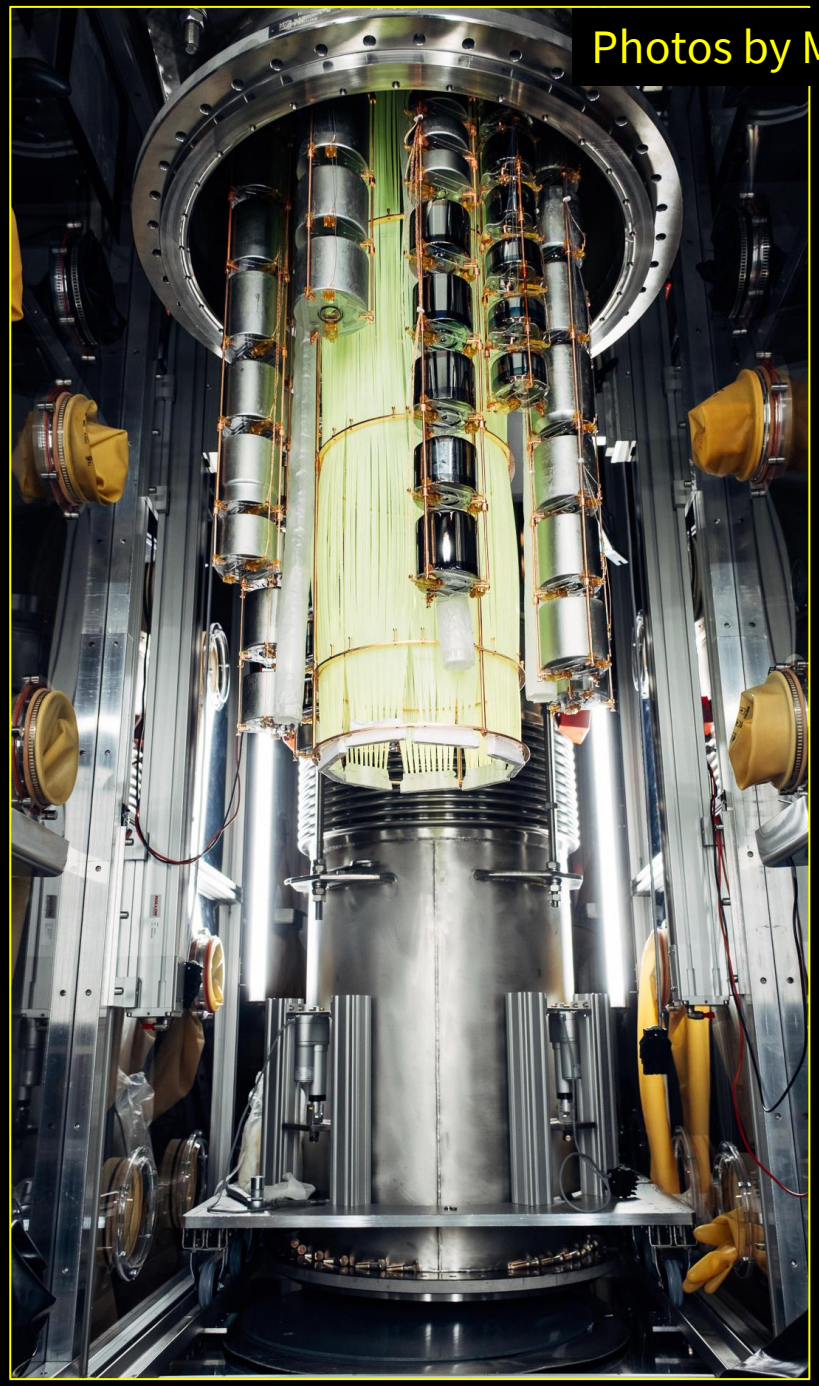
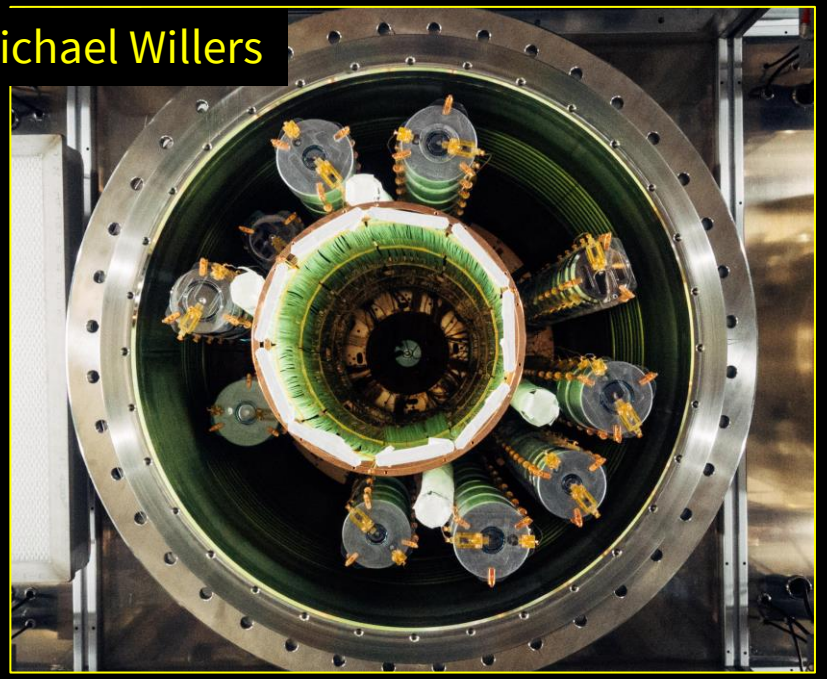
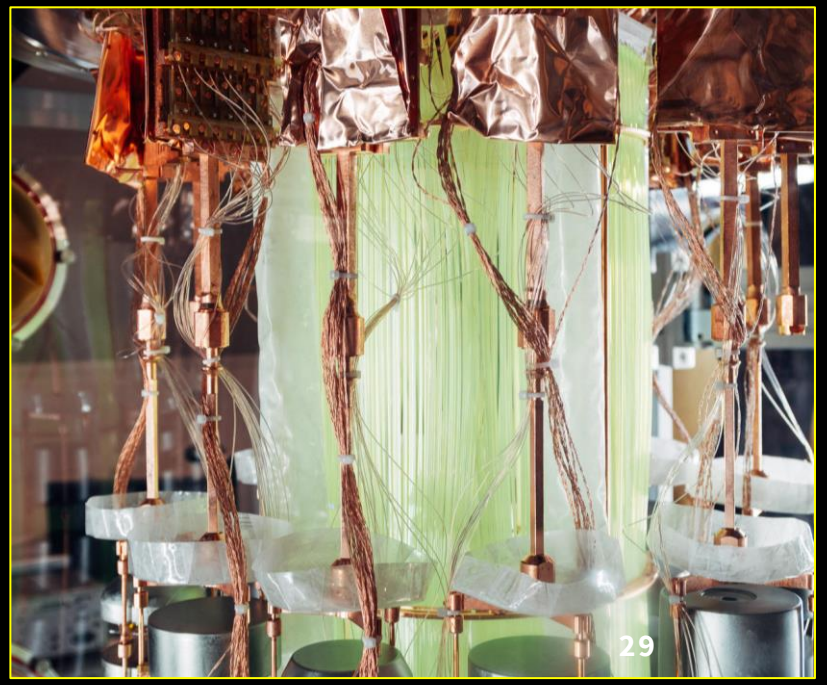






Simulated example spectrum: after cuts from 10 ton-years of data for LEGEND-1000

For 10 years of live time, LEGEND-1000 will probe 0νββ decay with 99.7% CL discovery sensitivity (a 50% chance of measuring a signal of at least 3σ significance for $T_{1/2}$ of 1.3×10^{28} years) corresponding to a $m_{\beta\beta}$ upper limit in the range of 9–21 meV.



Photos by Michael Willers