The LEGEND Neutrinoless Double Beta Decay Experiments

LEGEND

Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay

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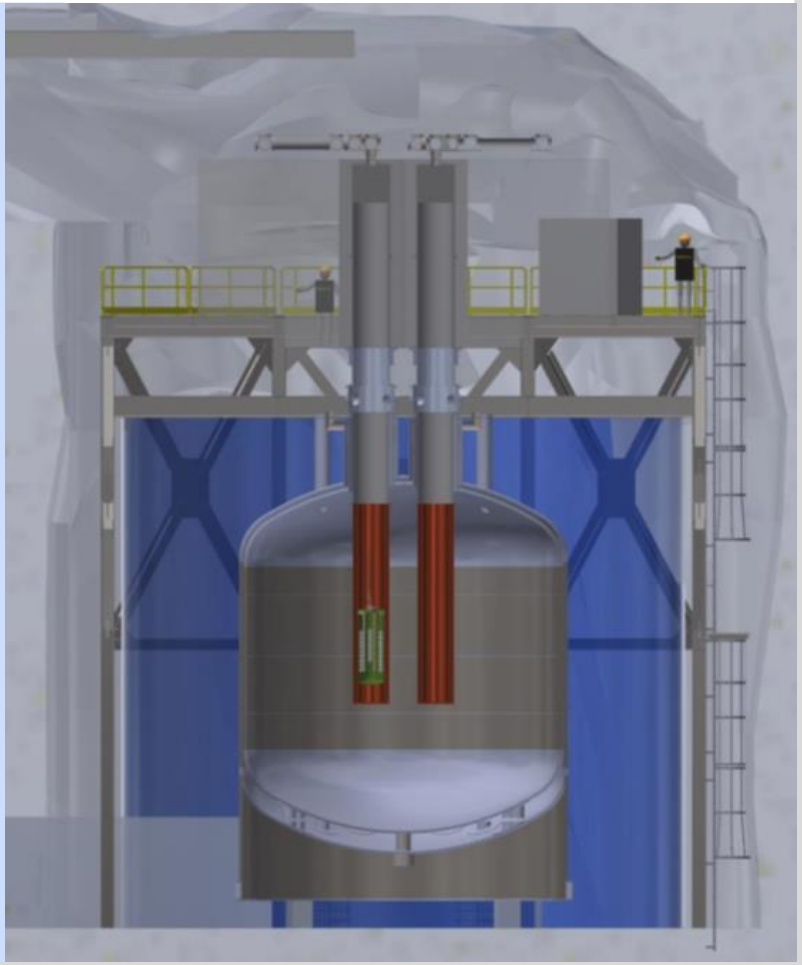
Canadian Association of Physicists Annual Congress



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Comenius Univ.
Czech Tech. Univ. Prague and IEAP
Daresbury Lab.
Duke Univ. and TUNL
Gran Sasso Science Inst.
Indiana Univ. Bloomington
Inst. Nucl. Res. Rus. Acad. Sci.
Jagiellonian Univ.
Joint Inst. for Nucl. Res.
Joint Res. Centre Geel
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Lancaster Univ.
Leibniz Inst. for Crystal Growth
Leibniz Inst. for Polymer Research
Los Alamos Natl. Lab.
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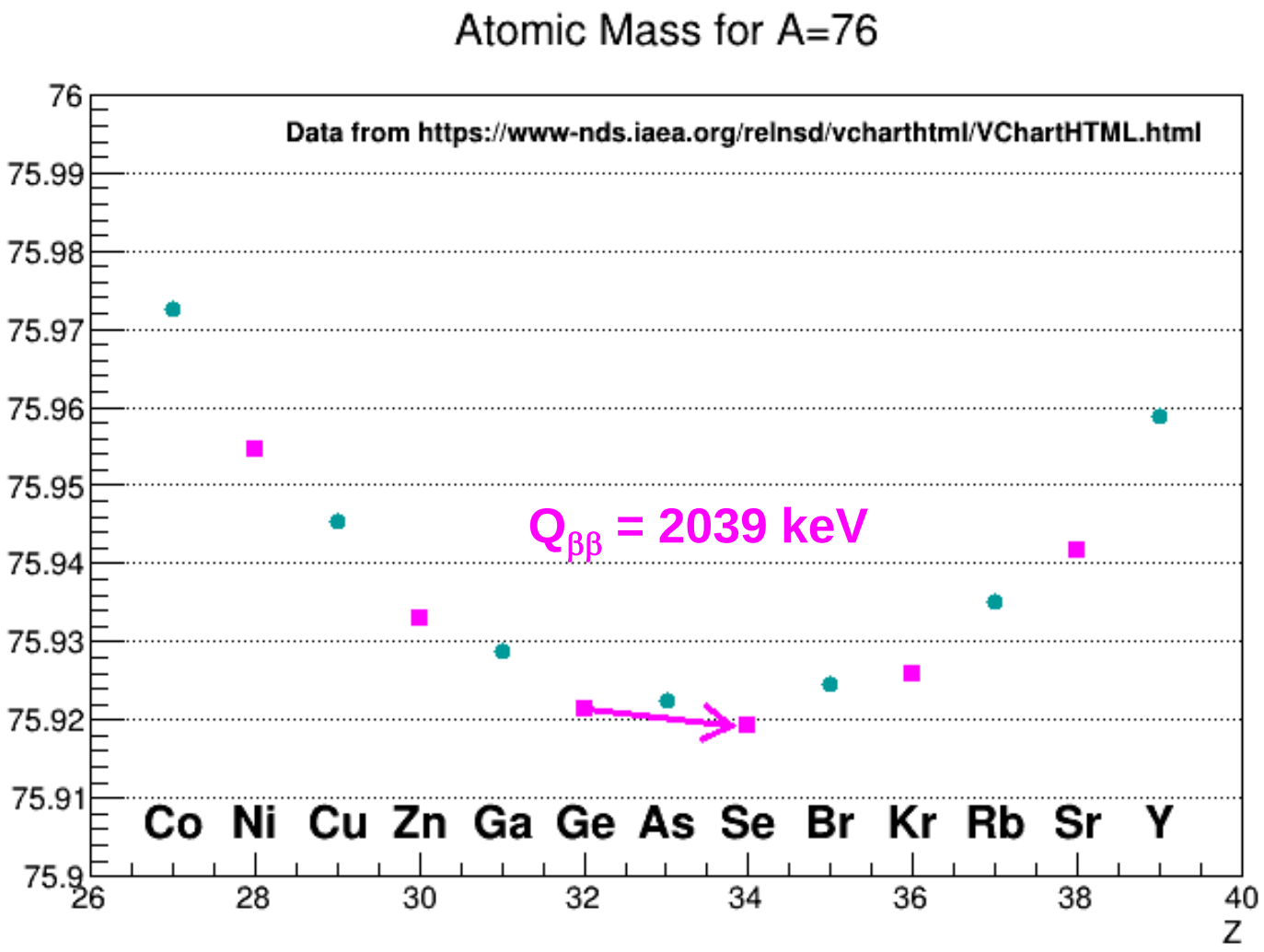
Univ. of Tennessee
Univ. of Texas at Austin
Univ. of Tuebingen
Univ. of Warwick
Univ. of Washington and CENPA
Univ. of Zurich
Williams College

Outline

- Double Beta Decay with Germanium Detectors
- LEGEND Concept and Background Control
- LEGEND-200 Results and Plans
- LEGEND-1000 Development

0νββ candidates are even-even nuclei as the mass parabola for odd-odd nuclei is shifted

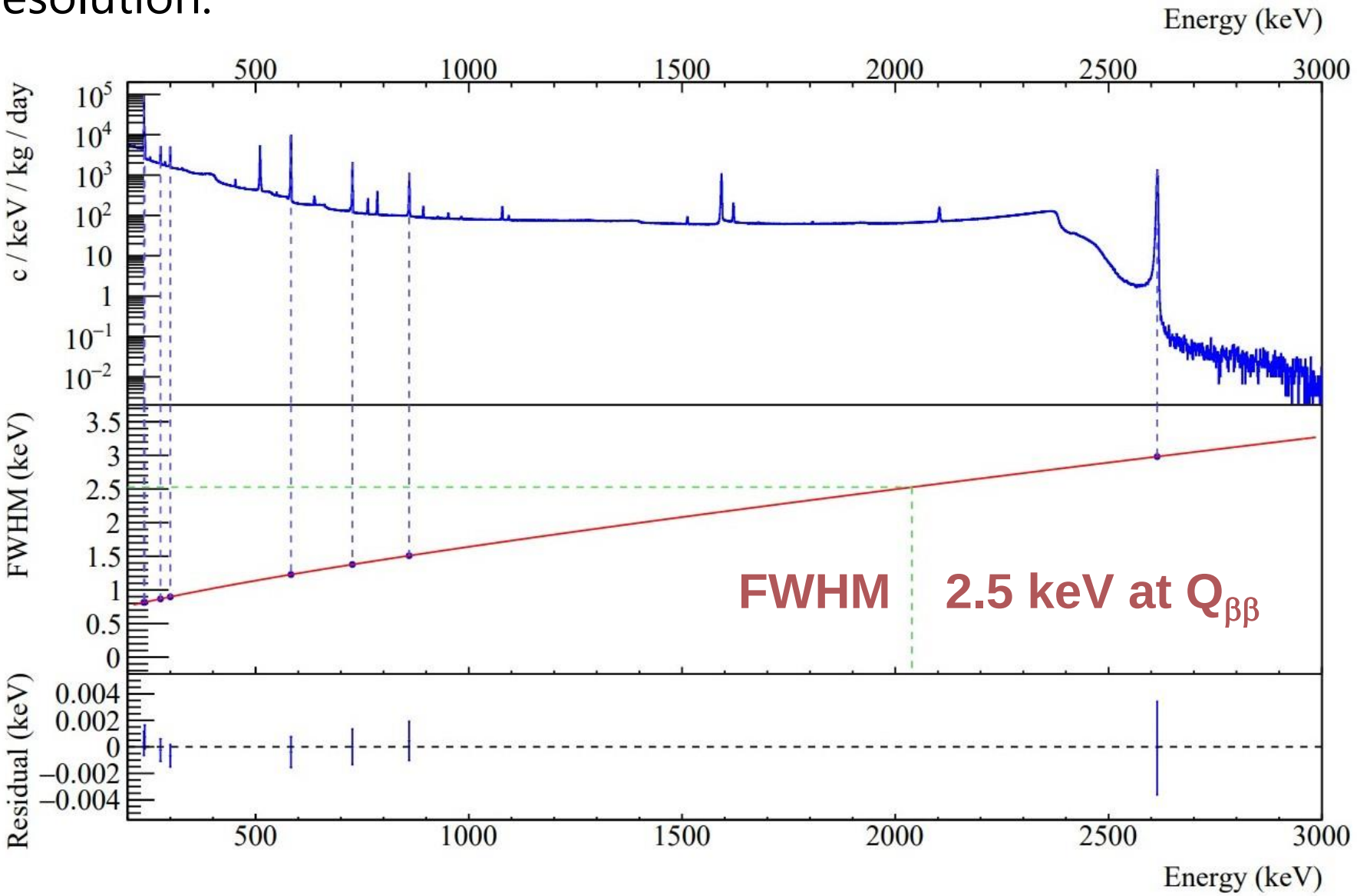


Odd odd nuclei

Even even nuclei

Single beta decay to As is energetically forbidden

Ge crystals with point-contact and electronics near crystal allows for exceptional pulse shape discrimination while maintaining energy resolution.

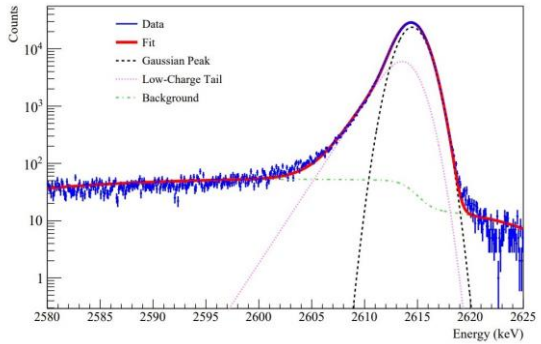


Combined energy calibration for DS0-6

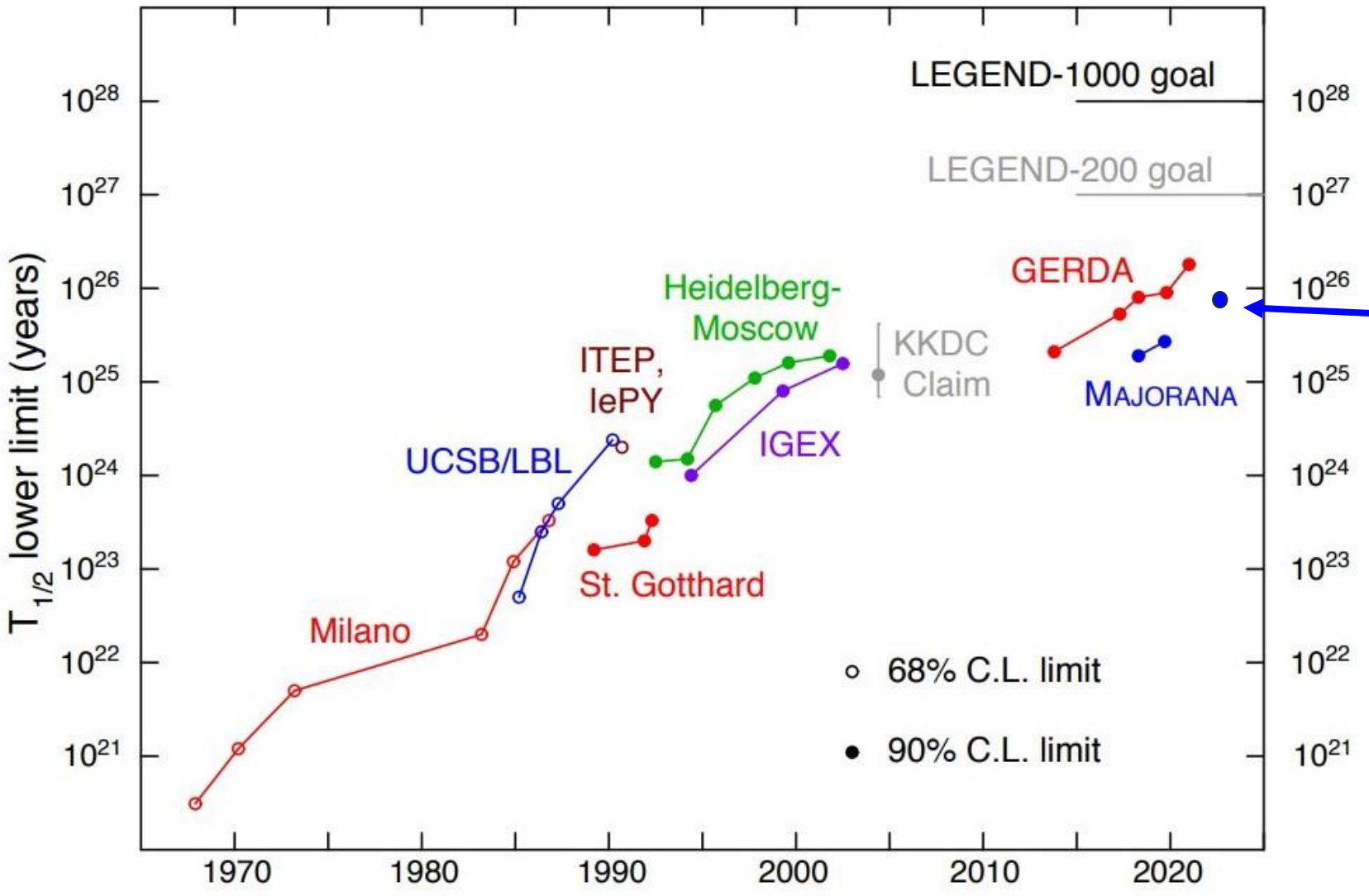
Majorana Demonstrator

https://arxiv.org/abs/1902.02299

Zoom into Tl-208 peak



Ge-76 has a long history in 0vbb searches



PRL 130, 062501 (2023)
$T_{1/2} > 8.3 \times 10^{25}$ yr (90%CL)

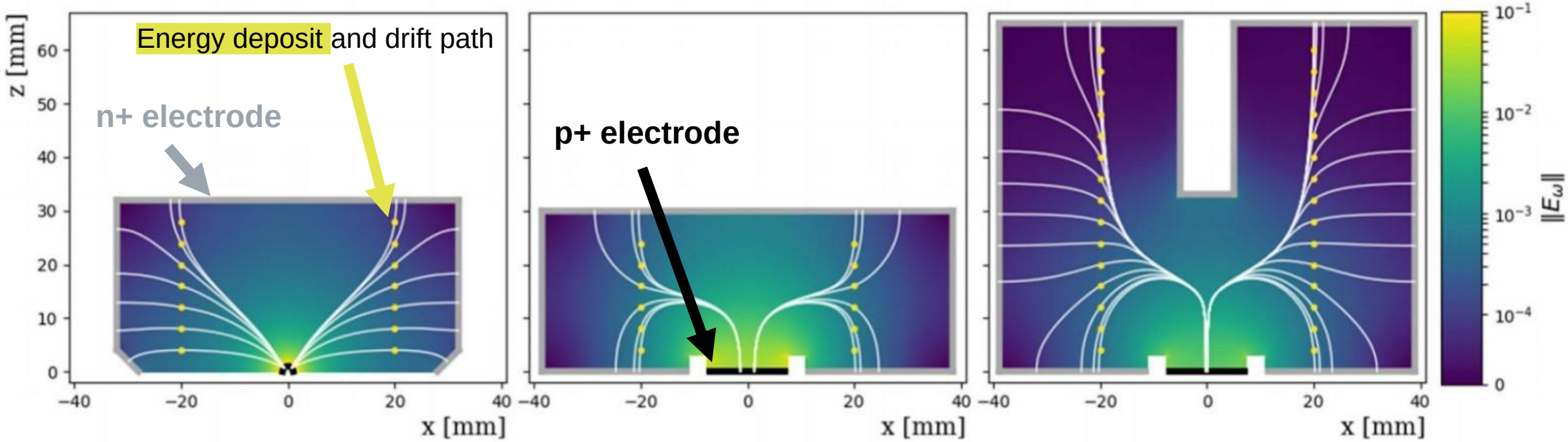
Data tabulated in review by Avignone and Elliott.
https://doi.org/10.3389/fphy.2019.00006
https://arXiv.org/abs/1901.02805

LEGEND uses sophisticated large enriched Ge-76 detectors building on work by Majorana and GERDA.

80 mm

60 mm

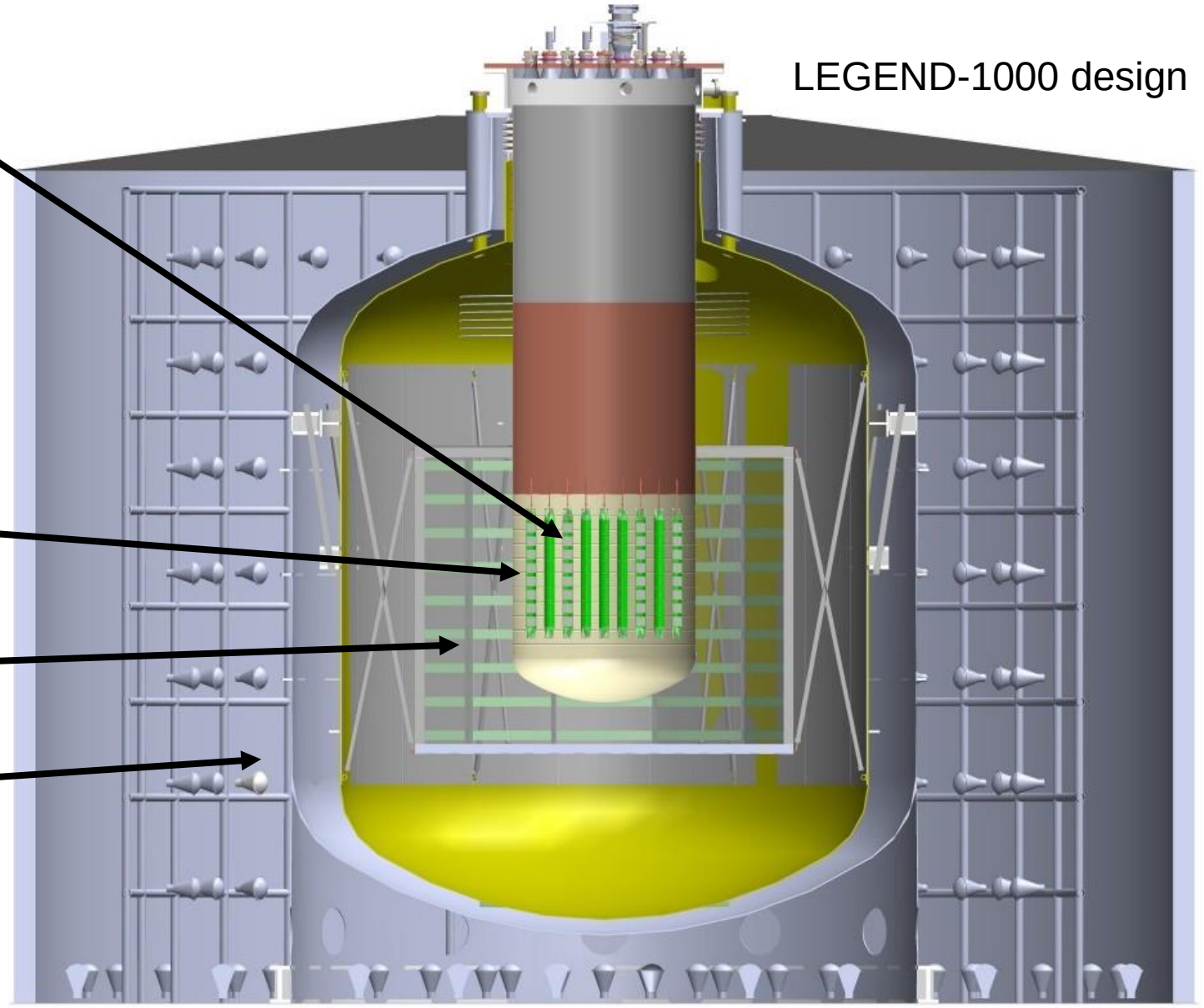
Inverted
Coaxial
Point
Contact



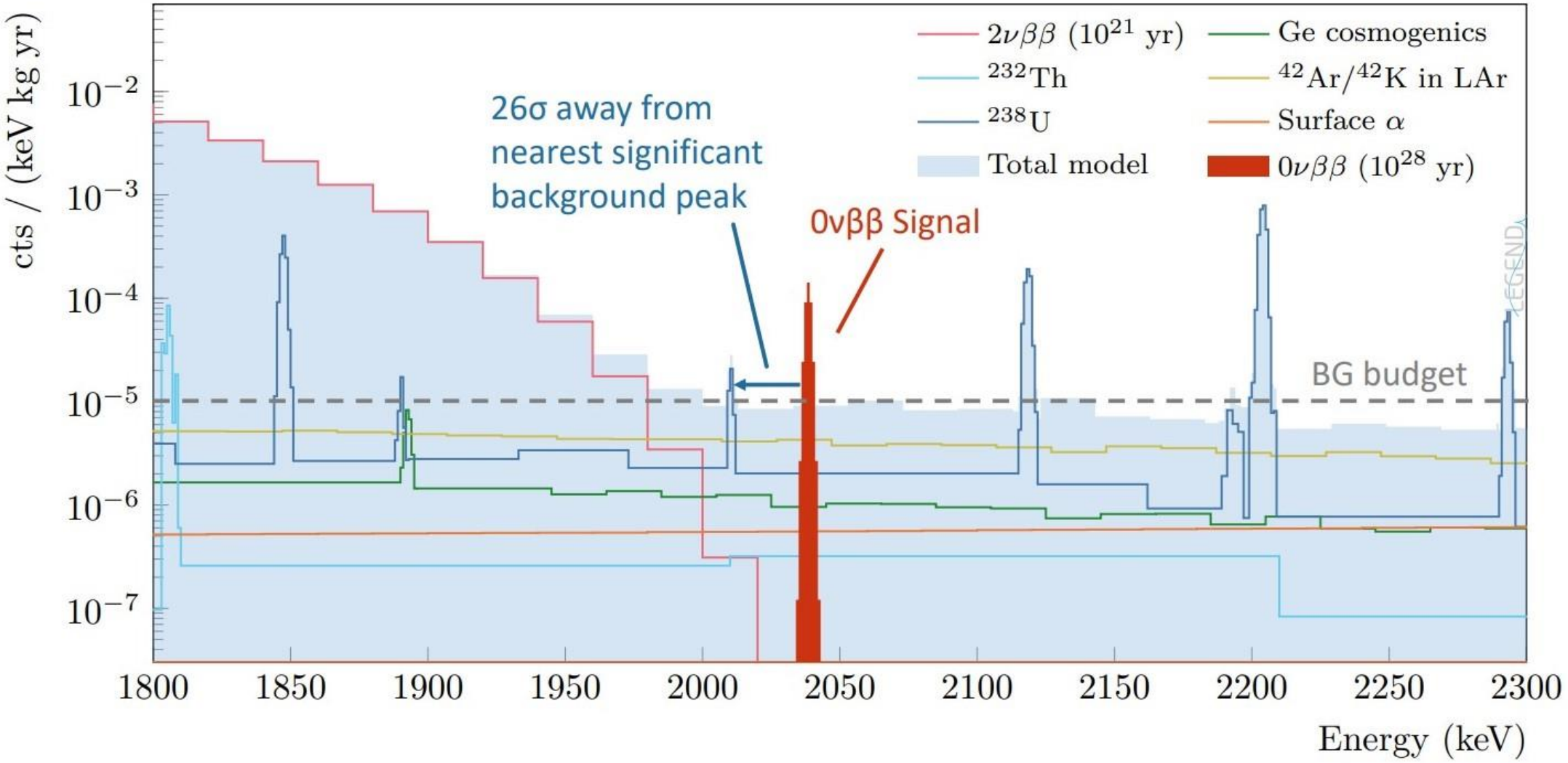
Majorana GERDA LEGEND

Many techniques are used to control background:

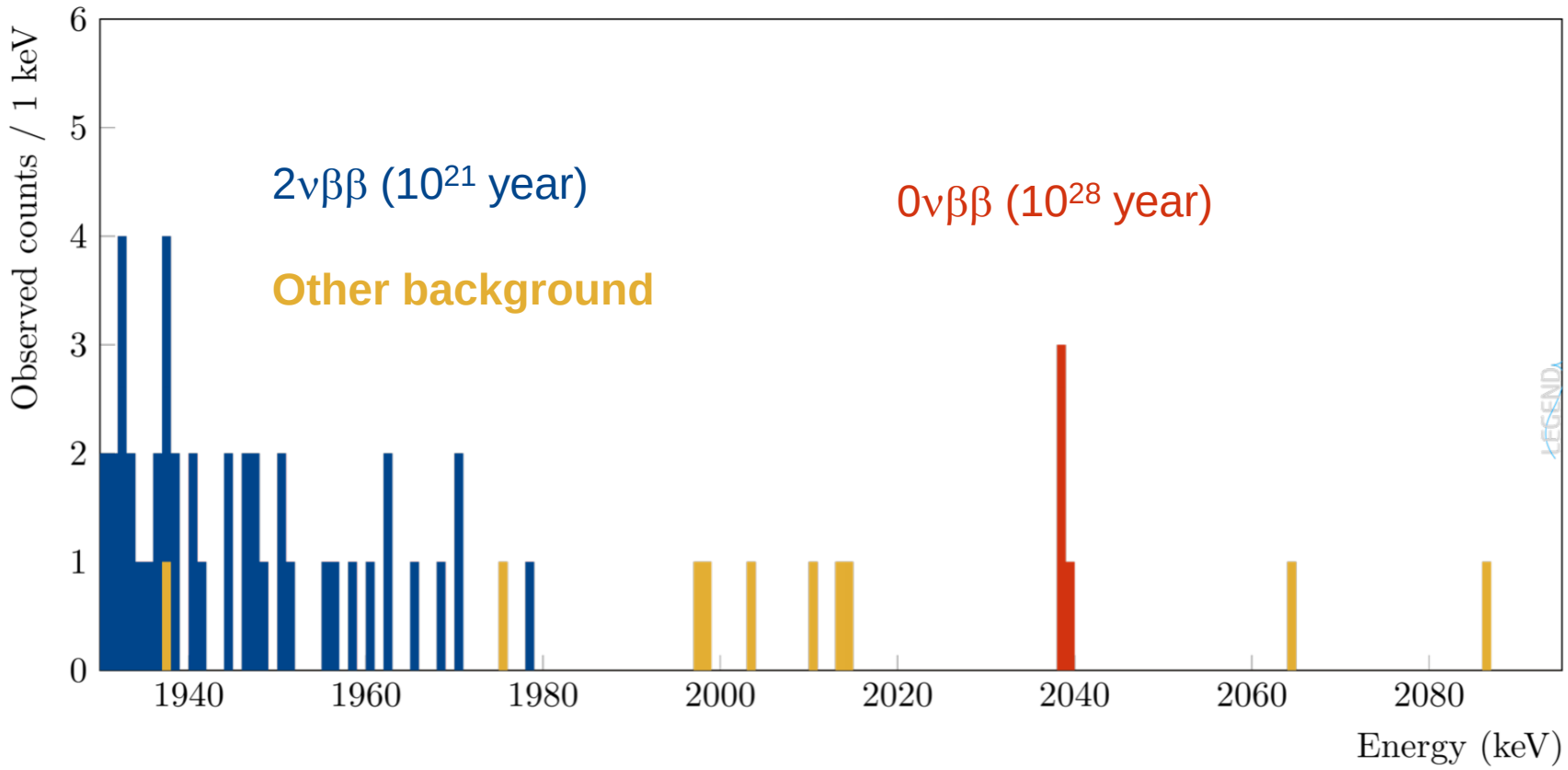
- Bare crystals with small-mass electronics (ASIC) near crystal:
  Exquisite energy resolution
- PSD in analysis to reject multi-site events
- Crystals in instrumented liquid-argon bath for cooling and Compton rejection.
  (Atmospheric Argon for LEGEND-200 and Underground Argon for LEGEND-1000)
- Instrumented atmospheric argon shield
- Instrumented water shielding tank



LEGEND-1000 Background Model

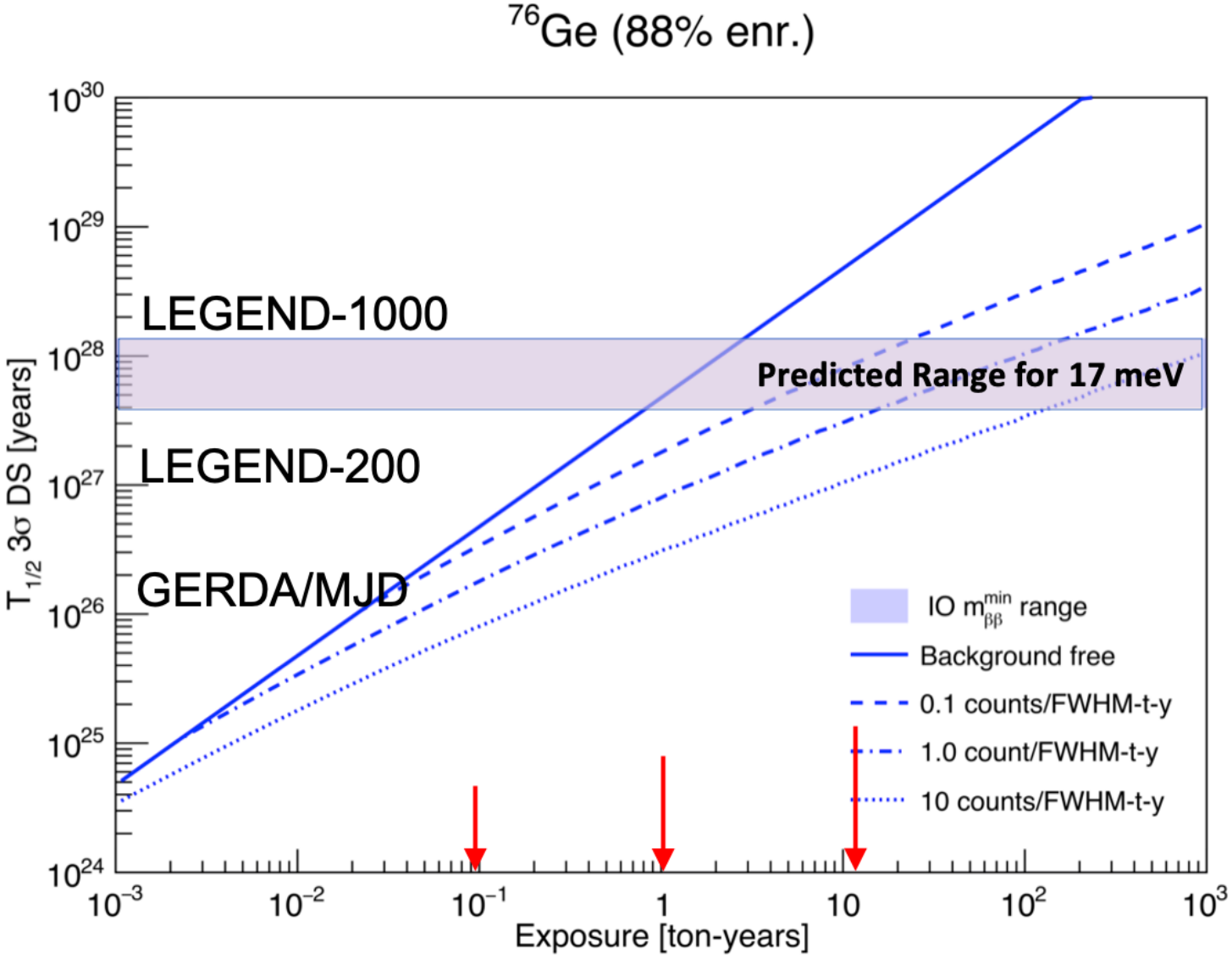


A sample 10 t-yr synthetic data set illustrates discovery potential



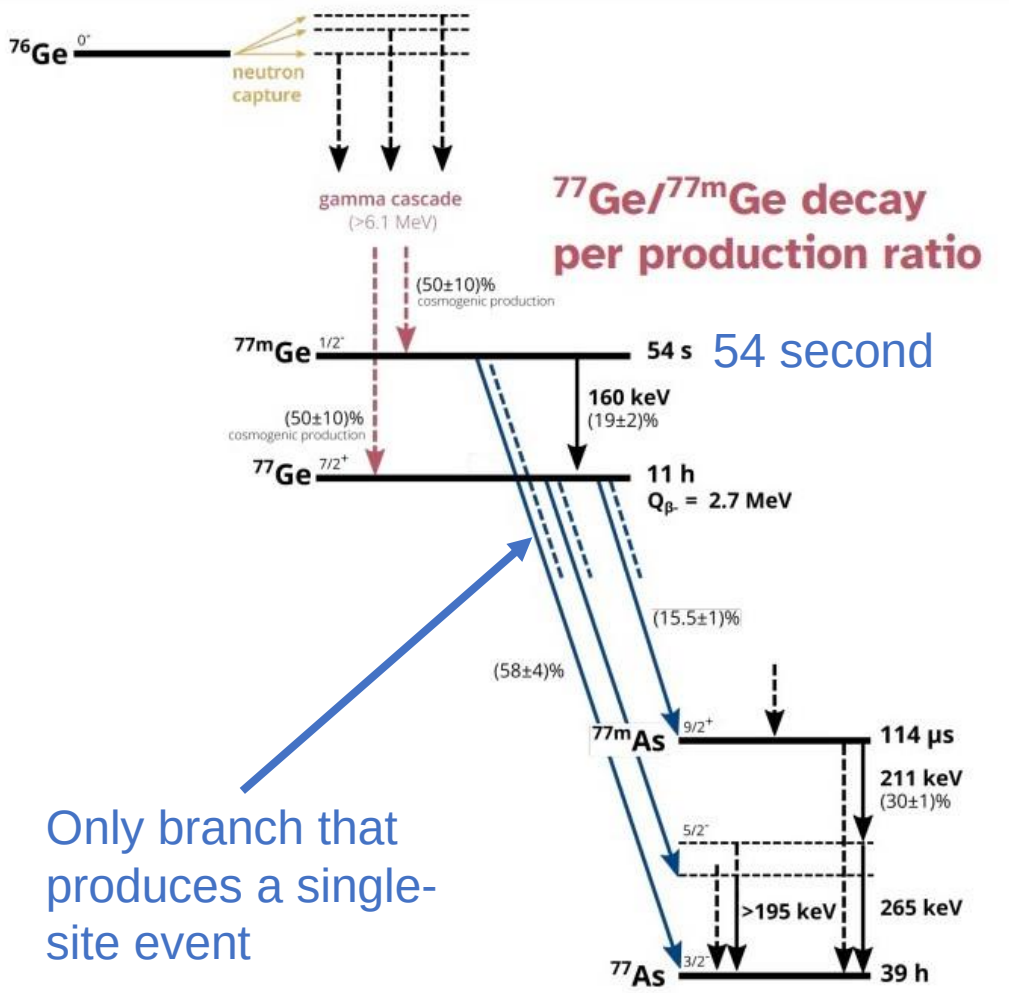
Discovery: a 50% chance or greater that a 10 tonne-year results in a signal 3σ above null hypothesis

LEGEND-1000 is designed to have $0\nu\beta\beta$ discovery potential at a 10^{28} year half life



Strategy for Suppressing Ge-77m Background (from cosmogenic activation of Ge-76)

- Acrylic panels are added to design in outer argon detector to thermalize neutrons
- A method for tagging cosmogenic fast neutrons has been developed in the instrumented outer (atmospheric) argon.
- Only one branch of Ge-77m produces a single-site event in LEGEND. Use a veto after a neutron signal.
- With a loss of ~3% detection efficiency, the total background rate at LNGS similar to that at SNOLAB.
- With this improvement in place, the physics reach at LNGS and SNOLAB are very similar.
- The detailed study will be published shortly
- A search for Ge-77m in LEGEND-200 is underway – will be upcoming publication.



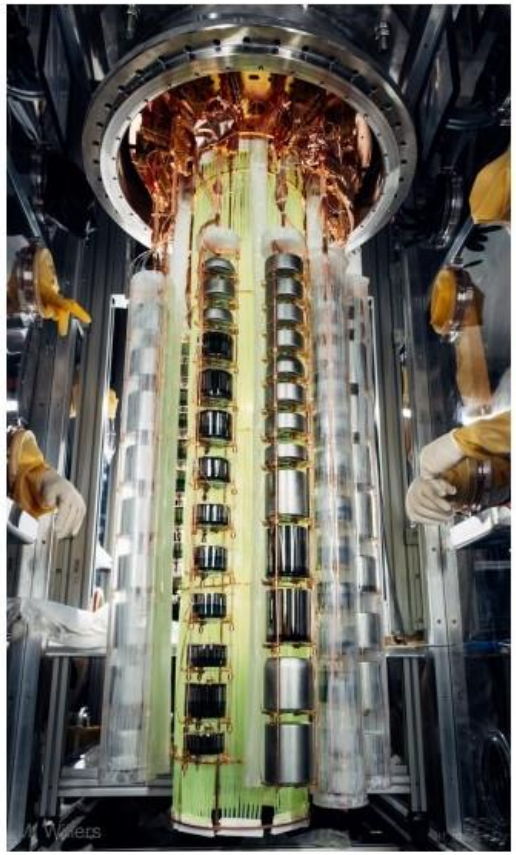
LEGEND-200 commissioning showing crystals and liquid argon readout

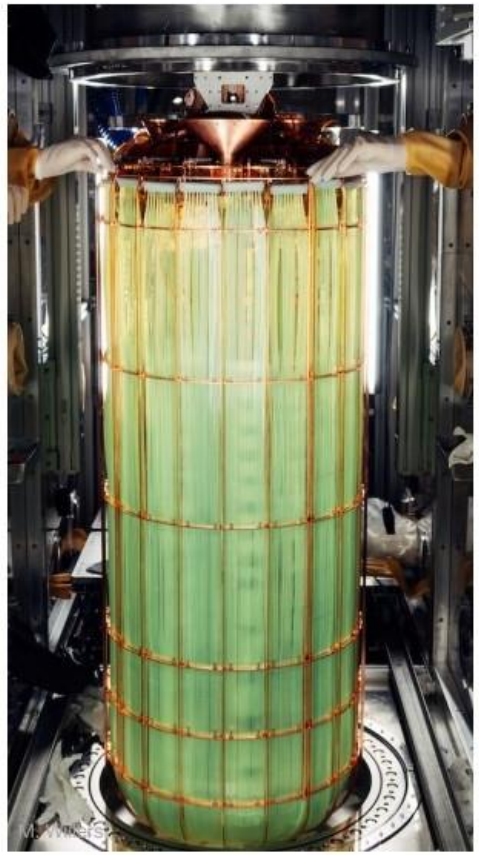

E. Sacchetti


Photo: E. Sacchetti

LAr instrumentation:
Construction & commissioning of LAr instr. hardware & readout electronics.

60 kg campaign:
First operation of 60 kg of HPGe detectors and full LAr instr.
Final hardware optimisations
Special calibration runs





142 kg installation:
Installation of all available HPGe detectors as well as full LAr installation, DAQ, readout electronics

Electronics & LAr instrumentation commissioning | 60 kg campaign + special calibration | 142 kg installation & commissioning | **Physics data taking**

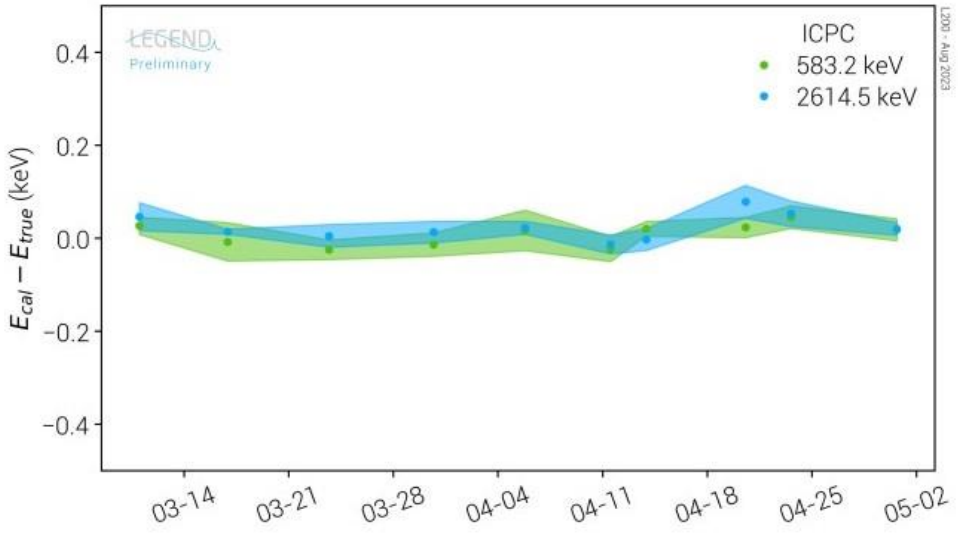
2022 — 2023

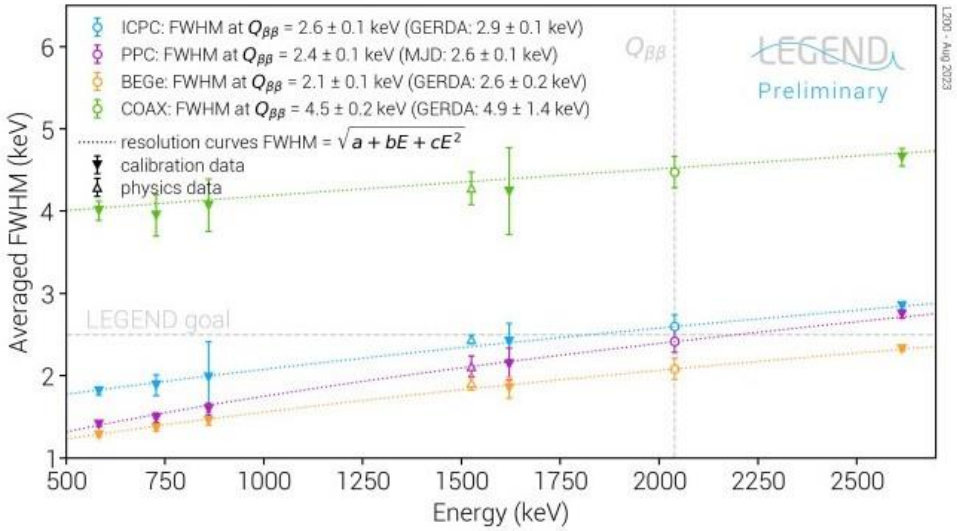
The first data release for LEGEND-200 at TAUP-2023

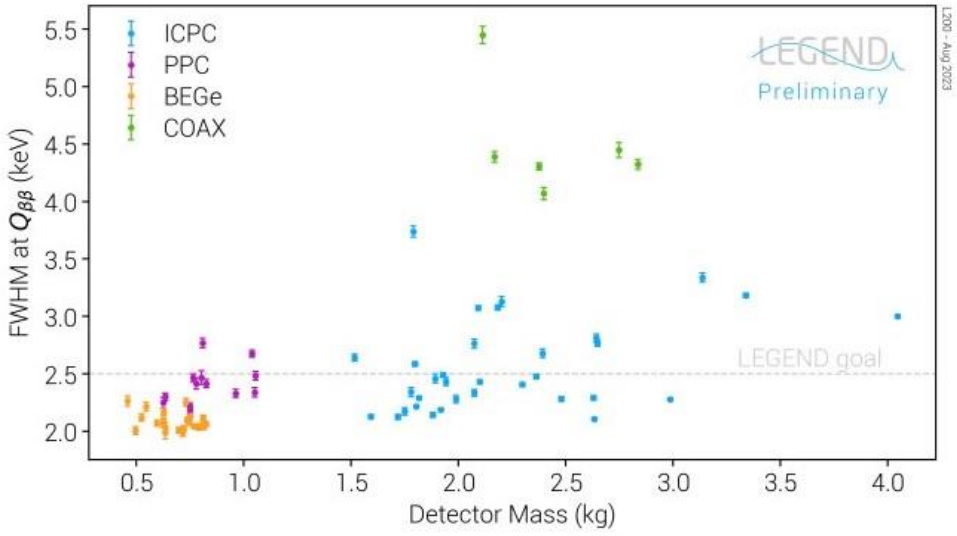
Energy Resolution & Stability

Weekly energy calibration between physics runs using ^{228}Th sources

- Overall improvement in energy resolution @ $Q_{\beta\beta}$
- Energy scale very stable between calibrations







LEGEND-200 highlights from TAUP-2023

Background Index

Wide background window: single event.

- First 10.1 kg yr of LEGEND-200 data
- ICPC & BEGe
- LAr accepted
- PSD accepted

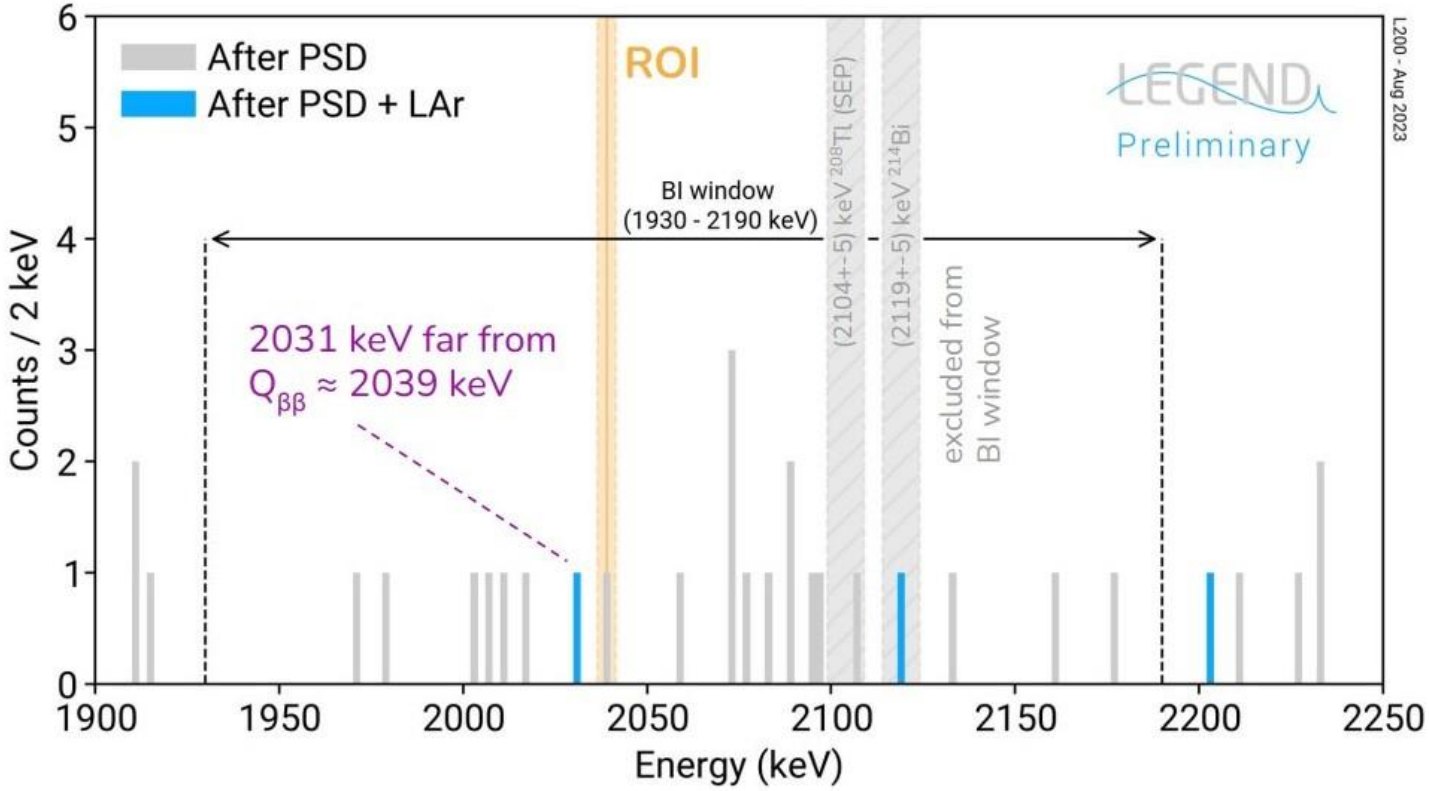
- BI is compatible with LEGEND-200 goal

  2×10^{-4} cts/(keV kg yr)

- Expect 0.48 cts
- Probability to observe

  #cts > 0 ~ 38%

window 240 keV & exposure 10.1 kg yr



	LEGEND-200 BI 68% CL (cts/keV/kg/yr)	GERDA Phase II unblinded BI 68% CL (cts/keV/kg/yr)
After LAr & PSD	4.1 [1.5,11.4] x 10^{-4}	5.2 [3.9,6.8] x 10^{-4}

The Next LEGEND-200 Data Release

- is planned for Neutrino 2024!

LEGEND-1000 Project Notes

- The DOE launched an ongoing process to examine alternatives for LEGEND-1000.
- Draft recommendations include
  - LEGEND-1000 is needed to meet the 10^{28} year half life sensitivity and therefore cover the inverted hierarchy space. (LEGEND-200 will reach 10^{27} years.)
  - LNGS is the baseline location. The LNGS site has reduced cost to the DOE while maintaining the physics goal.

Next Project Milestones: The CD-1 Process

- The US DOE Independent Project Review: week of June 3, 2024.
- Success in this review means CD-1 status is granted and the choice of LNGS as the site is made

Summary

- LEGEND-200 is running at LNGS with first detector-performance and background results released at TAUP-2023 and a second data release upcoming.
- LEGEND-1000 is in advanced design for deployment at LNGS with SNOLAB as the alternate site.
- The DOE CD-1 review is the week of June 3.
- 1000 kg of enriched Ge crystals with exquisite energy resolution in an ultra-low background environment have discovery potential with a half life of 10^{28} years for $0\nu\beta\beta$ in ^{76}Ge.