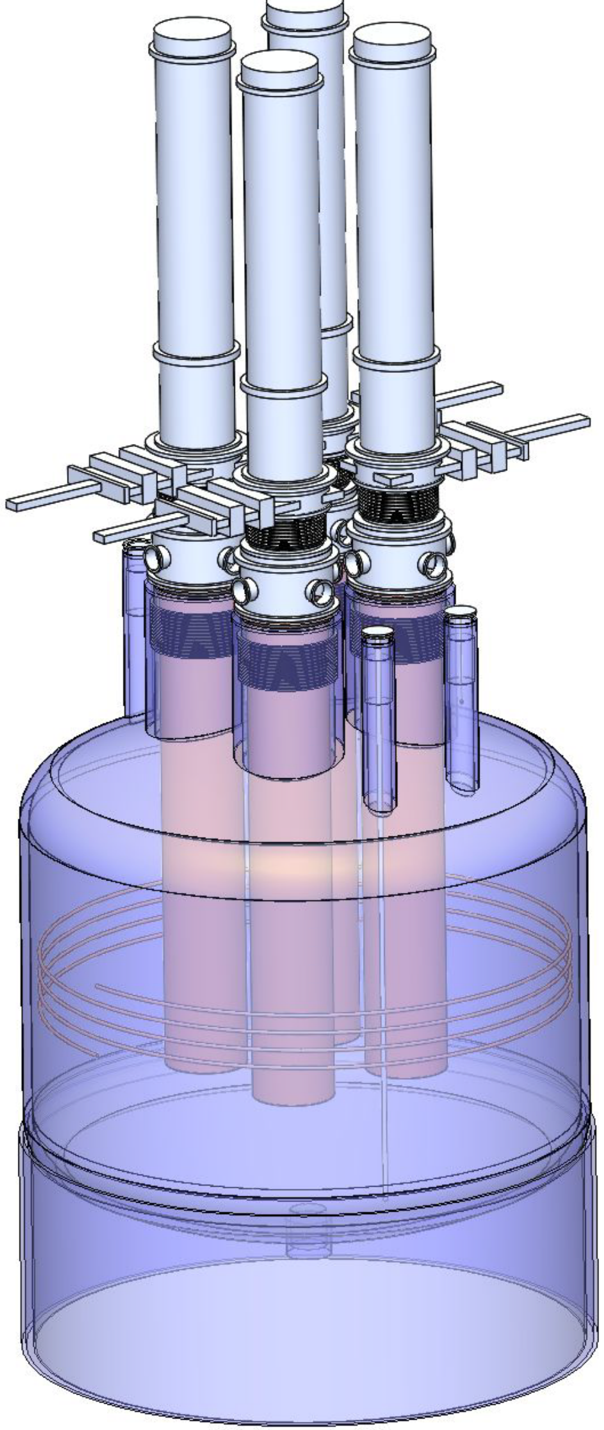

The Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay (LEGEND)

Gulden Othman

On Behalf of the LEGEND Collaboration

Lake Louise Winter Institute

13 February, 2020

TUNL Triangle Universities Nuclear Laboratory

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

U.S. DEPARTMENT OF ENERGY | Office of Science

NSF

The Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay (LEGEND)

Mission: “The collaboration aims to develop a phased, **Ge-76 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.**”

47 institutions, About 240 scientists

Univ. New Mexico
L'Aquila University and INFN
Lab. Naz. Gran Sasso
University Texas, Austin
Tsinghua University
Lawrence Berkeley Natl. Lab.
University California, Berkeley
Leibniz Inst. Crystal Growth
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Padova University
Padova INFN
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South Dakota School Mines Tech.
University Washington
Academia Sinica
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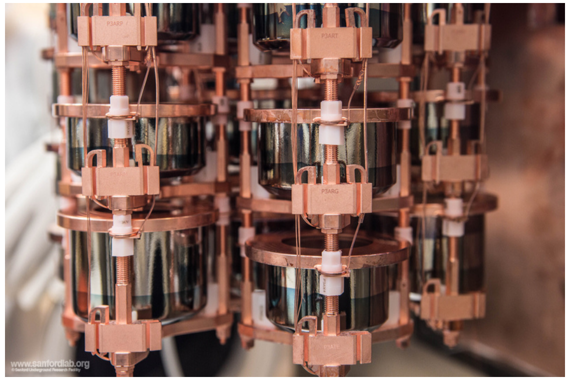
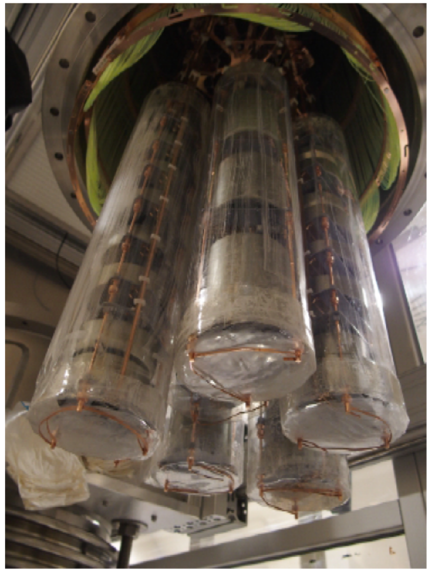
University South Dakota
University Zurich

The Best of MAJORANA & GERDA

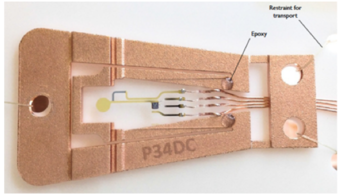


+



MAJORANA

- Radiopurity of nearby parts (FETs, cables, Cu mounts, etc.
- Low noise electronics improves pulse shape
- Low energy threshold (helps reject cosmogenic background)



Low-Mass Front-End

GERDA

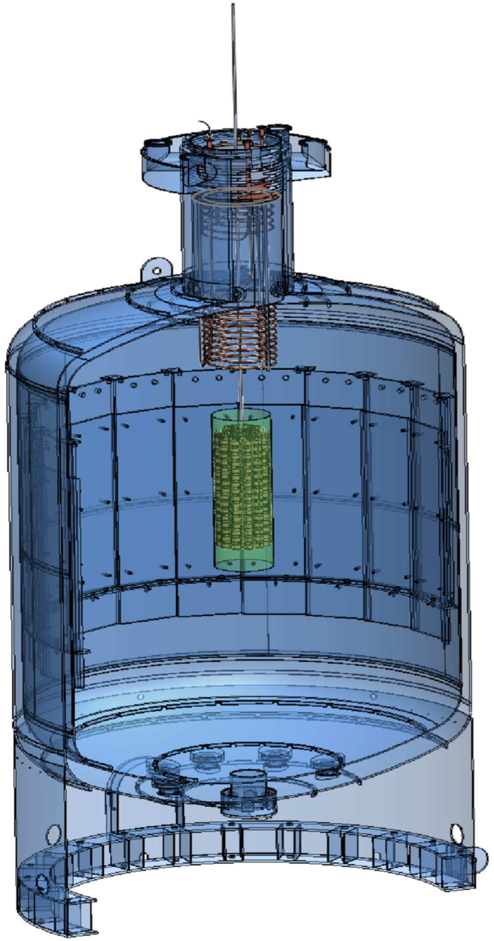
- LAr veto
- Low-A shield, no Pb

Both

- Clean fabrication techniques
- Control of surface exposure
- Development of large point-contact detectors
- Lowest background and best resolution $0\nu\beta\beta$ experiments

LEGEND (arXiv:1709.01980)

Method: Phased approach, selecting best technologies from GERDA and the MAJORANA DEMONSTRATOR, as well as contributions from other groups and experiments

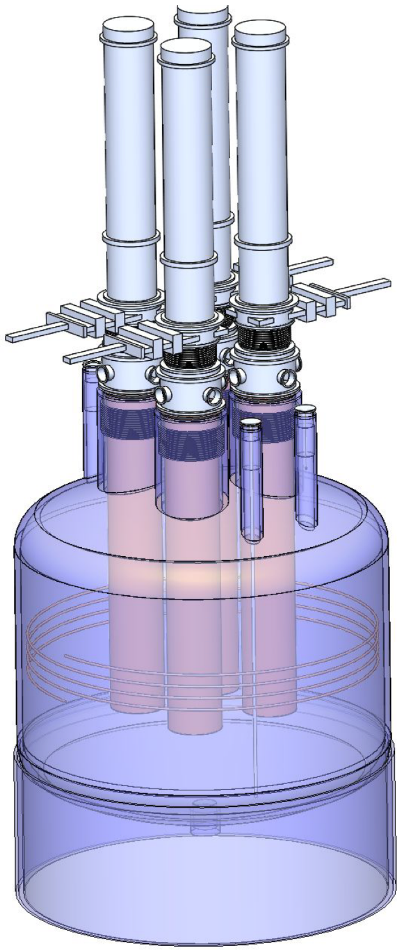


First phase:

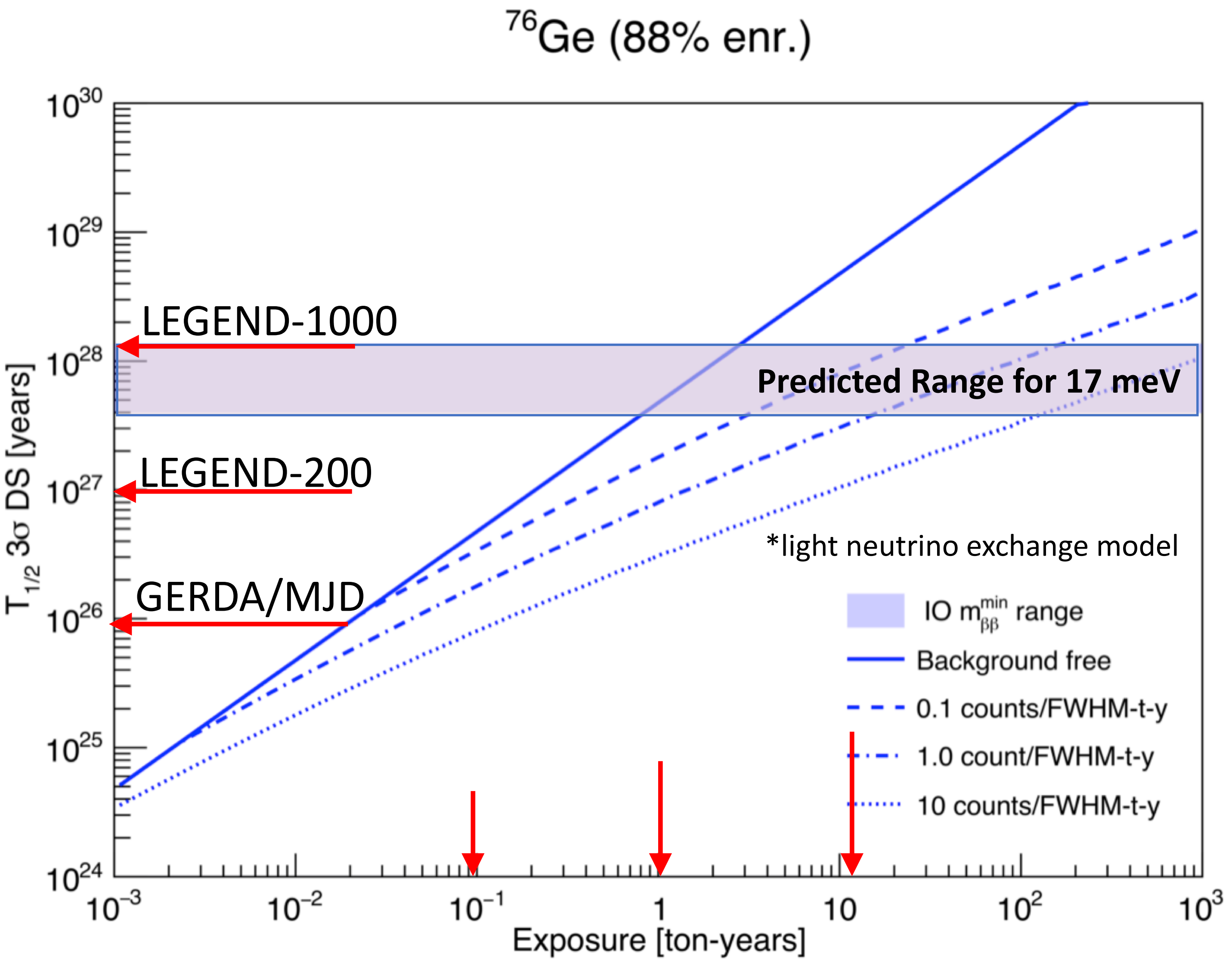
- 200 kg in upgrade of existing infrastructure at LNGS
- BG goal: **< 0.6 cts /(FWMH t yr)**
  < 2x10^{-4} cts /(keV kg yr)
- 3σ Discovery sensitivity at a half-life of 10^{27} years
- Data start ~2021

Subsequent phase:

- 1000 kg, staged in multiple payloads
- Timeline connected to review process
- Background goal **< 0.03 cts/(FWHM t yr)**
  < 1x10^{-5} cts/(keV kg yr)
- Location to be selected



LEGEND Discovery Potential



Goal is to cover inverted ordering (IO)* with 3σ CL Discovery Potential:

$$T_{1/2}^{0\nu\beta\beta} > 10^{28} \text{ yr}$$

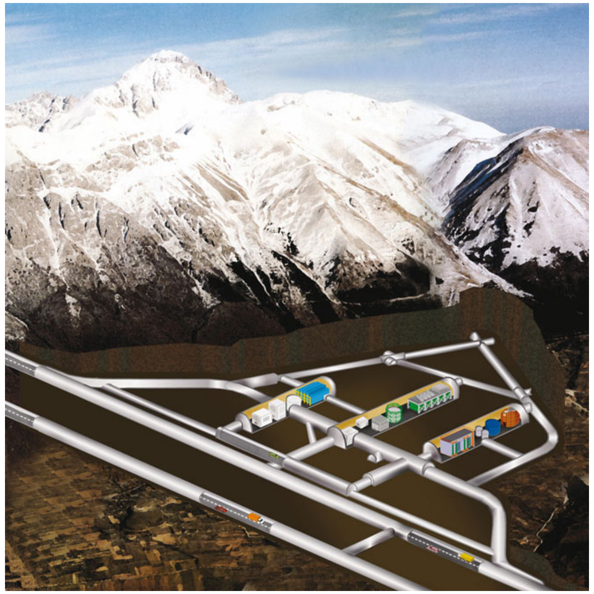
* light Majorana neutrino exchange
* using LSM matrix element of 3.5
* unquenched g_A
* sensitivity to IO $m_{\beta\beta}$= 17 meV

GERDA has achieved lowest background index:
6.0 x 10^{-4} cts /kev kg yr at $Q_{\beta\beta}$

MAJORANA has achieved best energy resolution:
2.5 keV FWHM at $Q_{\beta\beta}$

LEGEND-200

Existing GERDA infrastructure can hold 200 kg of enriched detectors

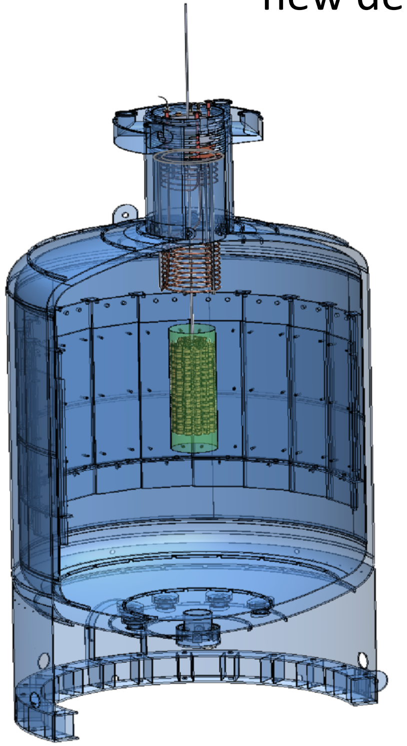


LNGS: Hall A

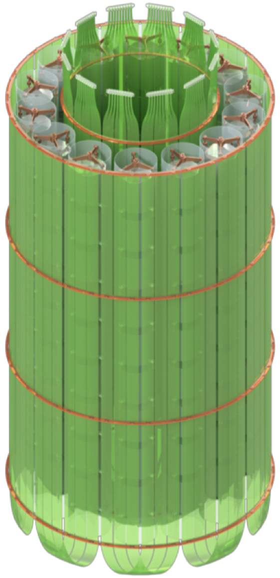
Water tank, modified clean room from GERDA

Upgraded LAr cryostat:

- new lock
- new detector mounting hardware

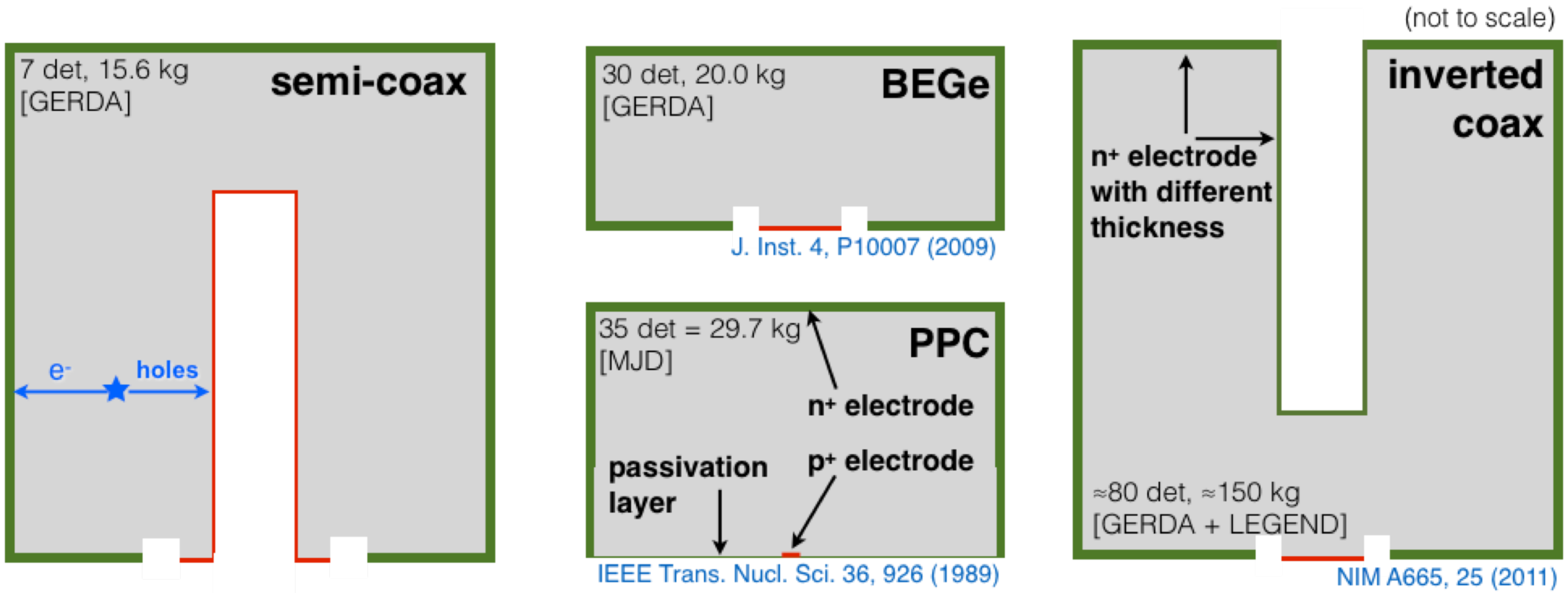


14 strings



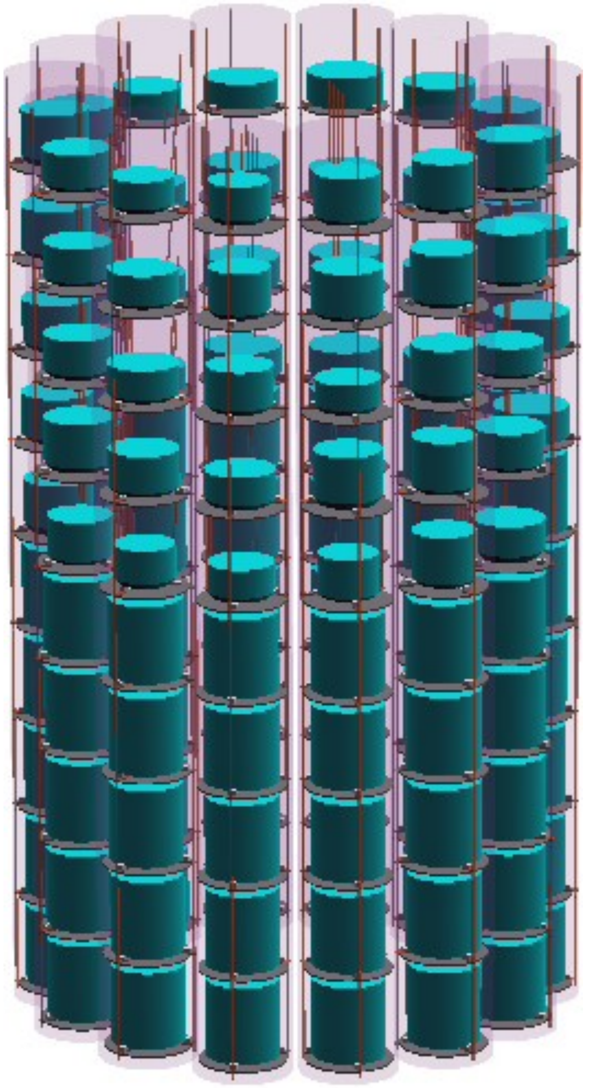
LAr active veto: Optical fibers surround detector strings

Ge detectors for LEGEND-200

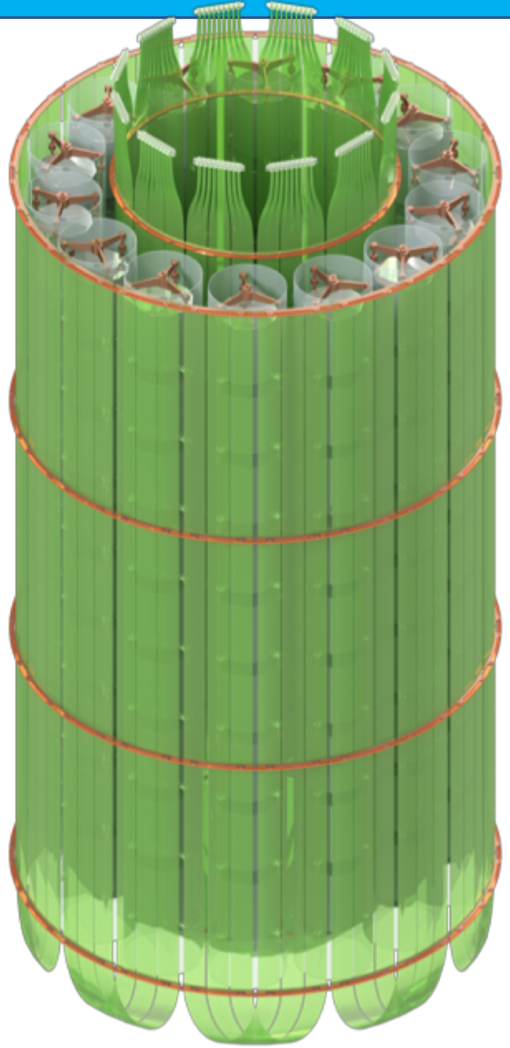


- Majorana and GERDA detectors will make up ~60 kg of the detector mass
- The remaining mass will come from a new geometry of detectors being manufactured by two companies: ORTEC and Mirion (~80 detectors)

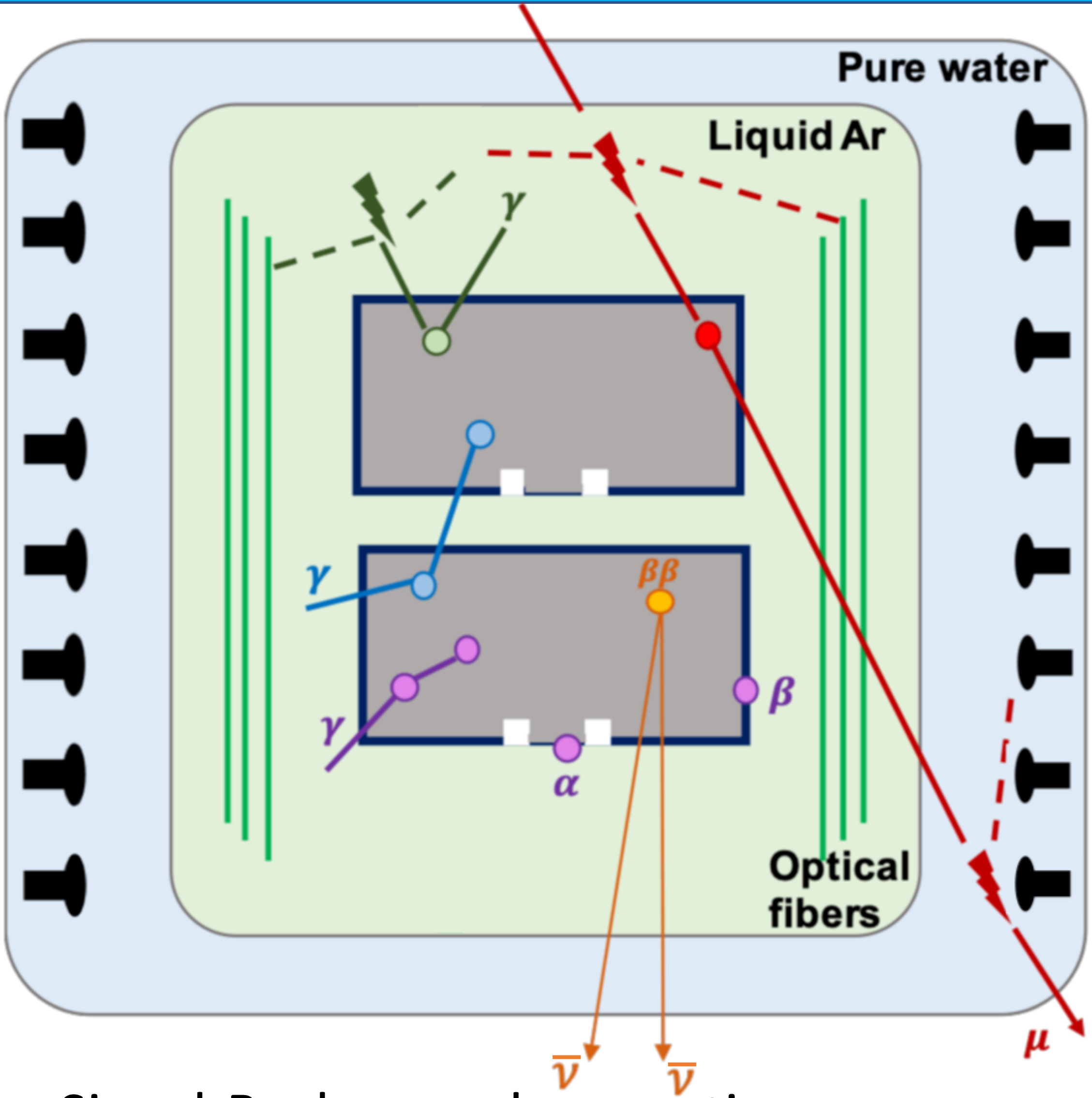
•4 different detector types for LEGEND-200
•Different surface-to-volume ratios
•Different surface areas: n+ , p+ and passivation layer (PL)
•Subject to alpha and beta radiation in LAr



Background Reduction Strategy



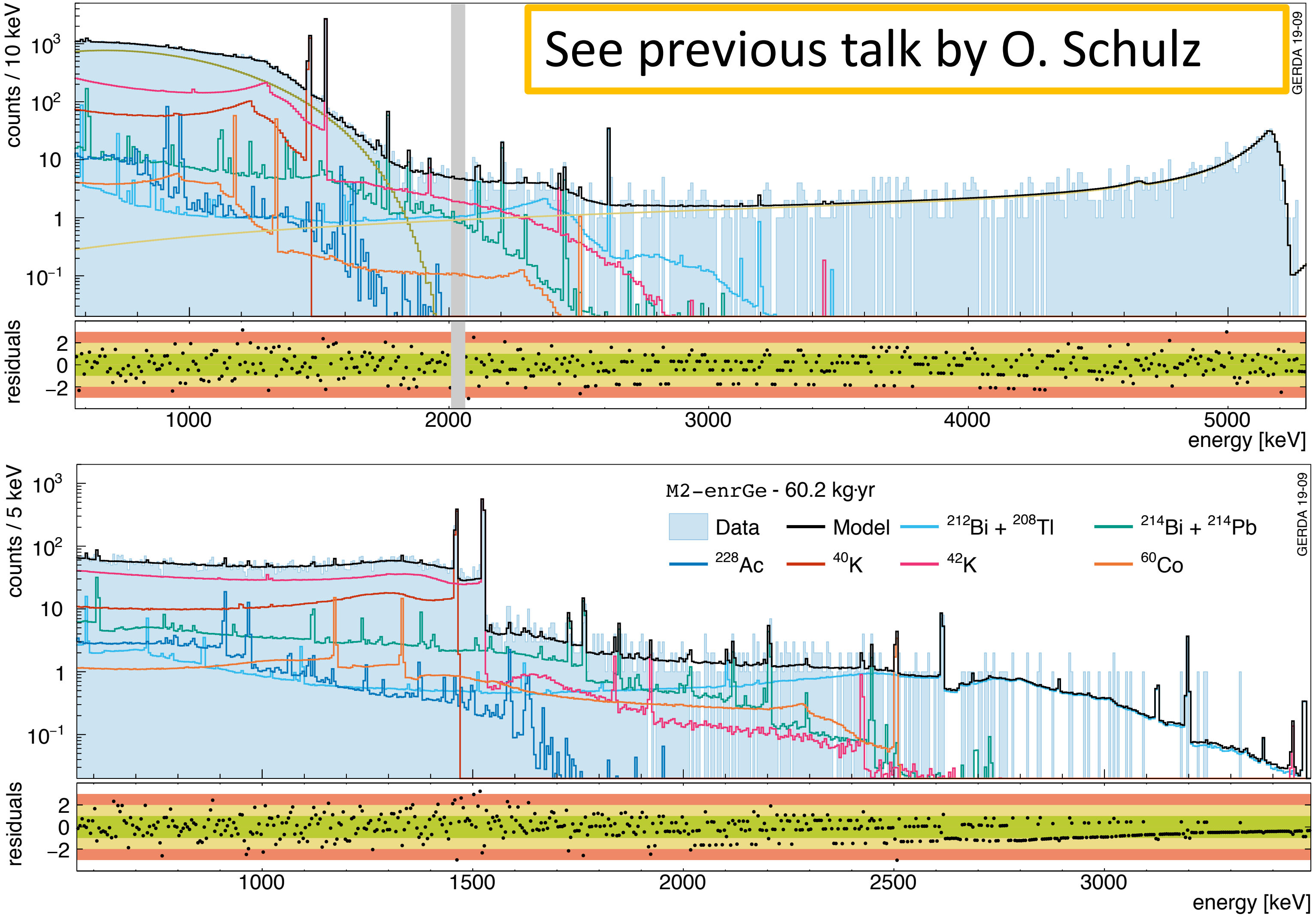
LEGEND-200 LAr readout design



Signal-Background separation

LEGEND-200 Backgrounds Projections: GERDA Phase II

Background contributions in LEGEND-200 expected to be very similar to GERDA Phase II



- α from ^{210}Po, ^{226}Rn
- β from ^{42}K
- γ from ^{214}Bi, ^{208}Tl

GERDA Phase II:

Science 365, 1445 (2019)

arXiv:1909.02522

LEGEND-200: Background Reduction

LEGEND

Background reduction of at least x5 compared to GERDA/MAJORANA

Feasibility of reducing backgrounds from ^{42}K, ^{214}Bi, ^{208}Tl has already been shown in GERDA, MAJORANA, and in dedicated test stands

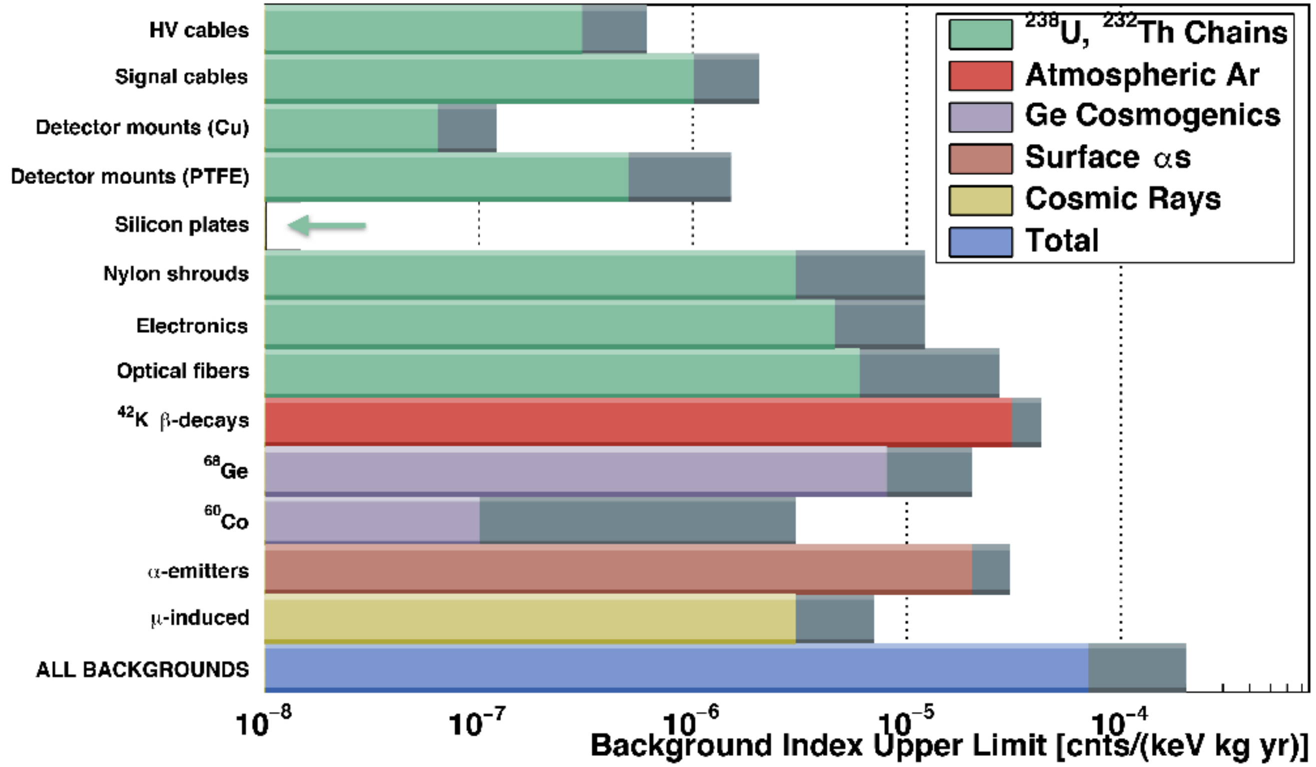
- Improved radiopurity levels (cables, electro-formed Cu, PTFE, ...)
- Increased detector mass (≥x2) :
  - → proportional reduction from near-by parts
  - → better surface/volume ratio, reducing surface backgrounds
- Higher purity LAr → increased scintillation light yield and attenuation length
- Improved detection and readout of LAr scintillation light
- Reduction of electronic noise → improved PSD
- Optimized PSD analysis for surface events

^{214}Bi /^{208}Tl

^{42}K

LEGEND-200 Background Projections

Assay limits correspond to the 90% CL upper limit. Grey bands indicate uncertainties in overall background rejection efficiency



Monte Carlo simulations based on experimental data and material assays.

Background rates after anti-coincidence, LAr veto, and PSD cuts

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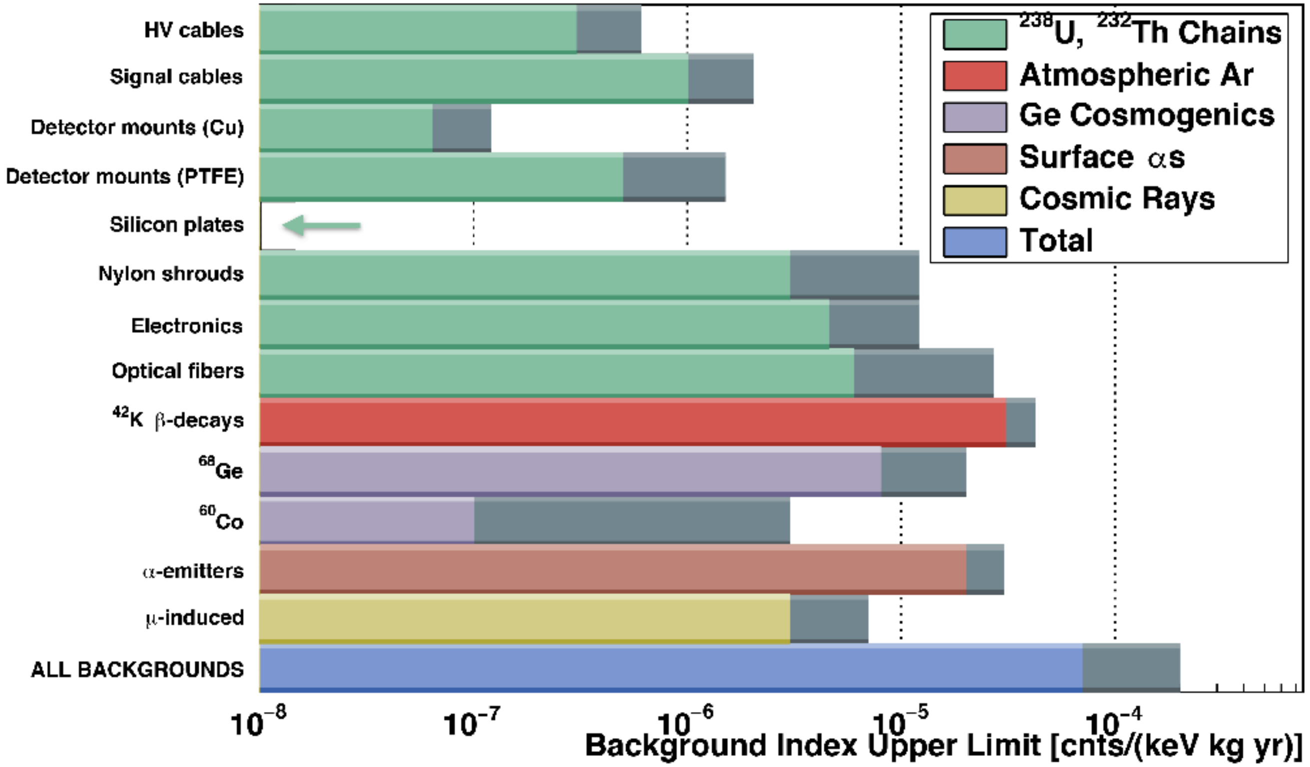
Assay limits correspond to the 90% CL upper limit. Grey bands indicate uncertainties in overall background rejection efficiency



Monte Carlo simulations based on experimental data and material assays.

Background rates after anti-coincidence, LAr veto, and PSD cuts

Background index upper limit: **(0.7–2.0)x10^{-4} cts/(keV kg yr)** or **0.2–0.5 cts/(FWHM t yr)** at $Q_{\beta\beta}$

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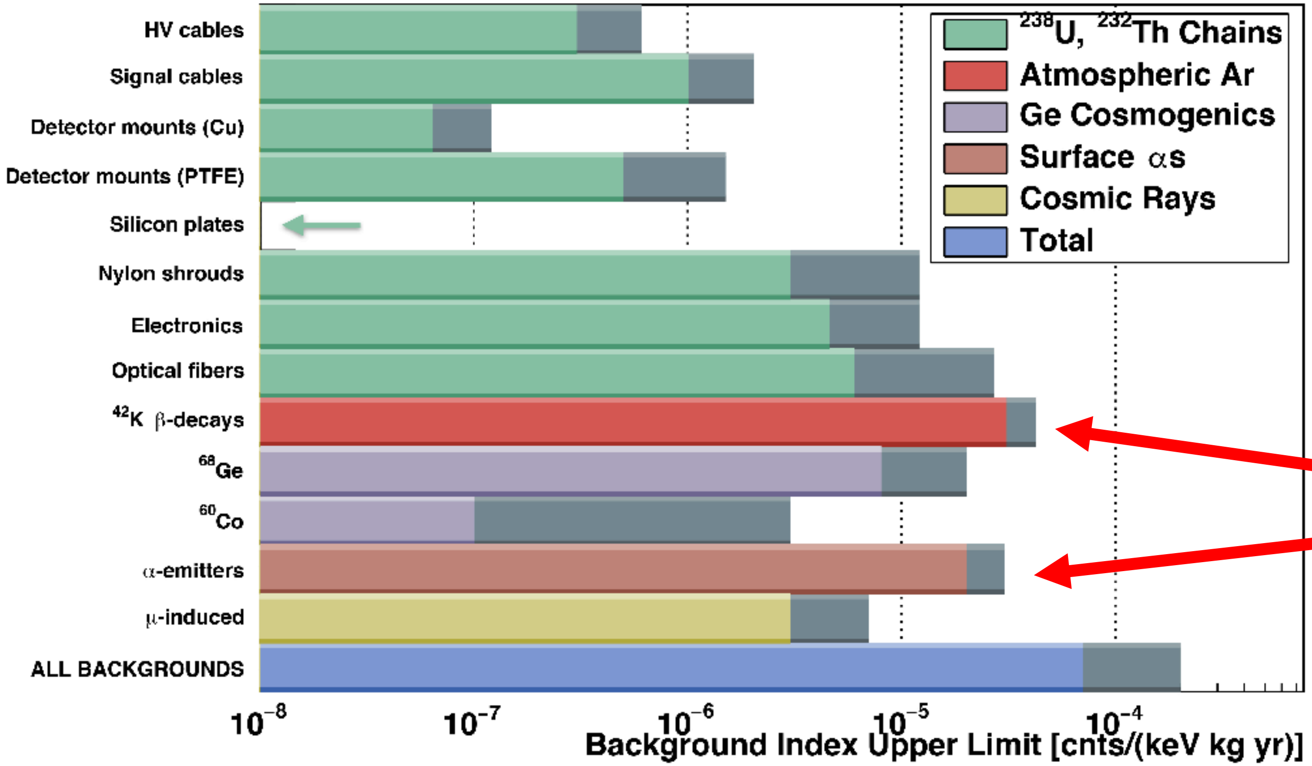

Monte Carlo simulations based on experimental data and material assays.

Background rates after anti-coincidence, LAr veto, and PSD cuts

Surface events from alphas and betas projected to be largest background contribution

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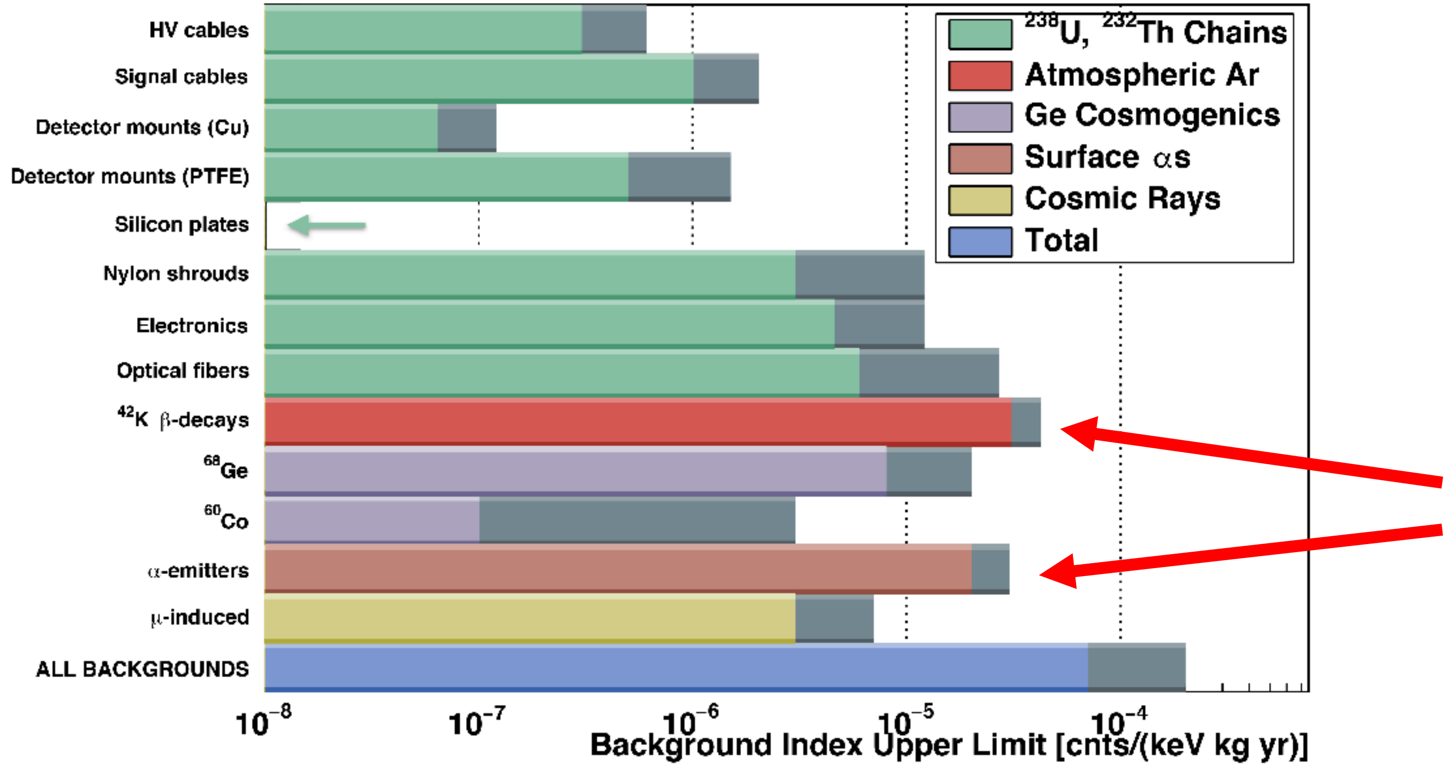

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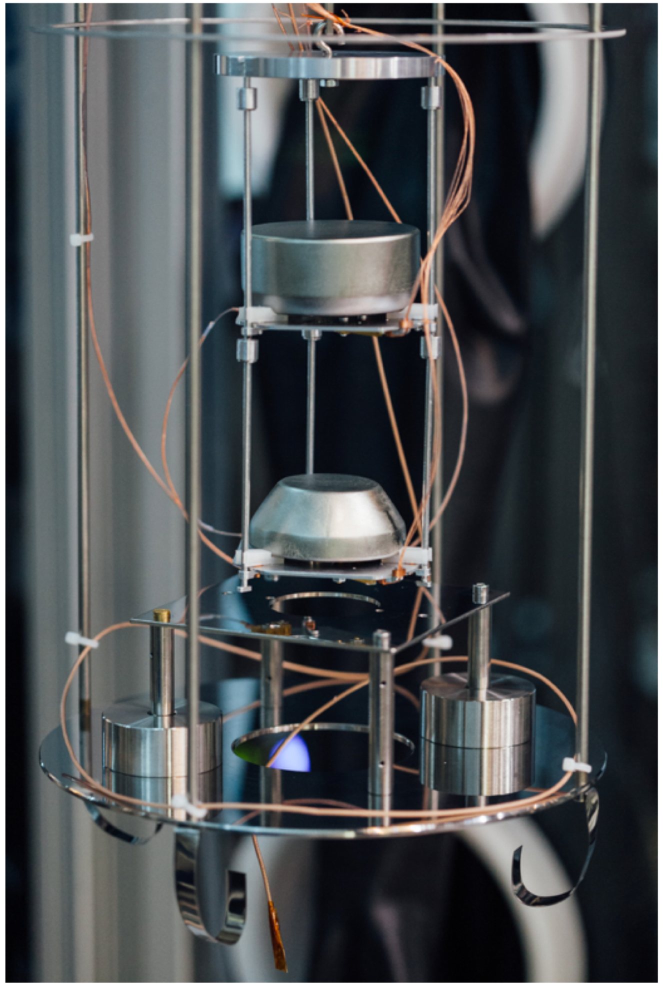
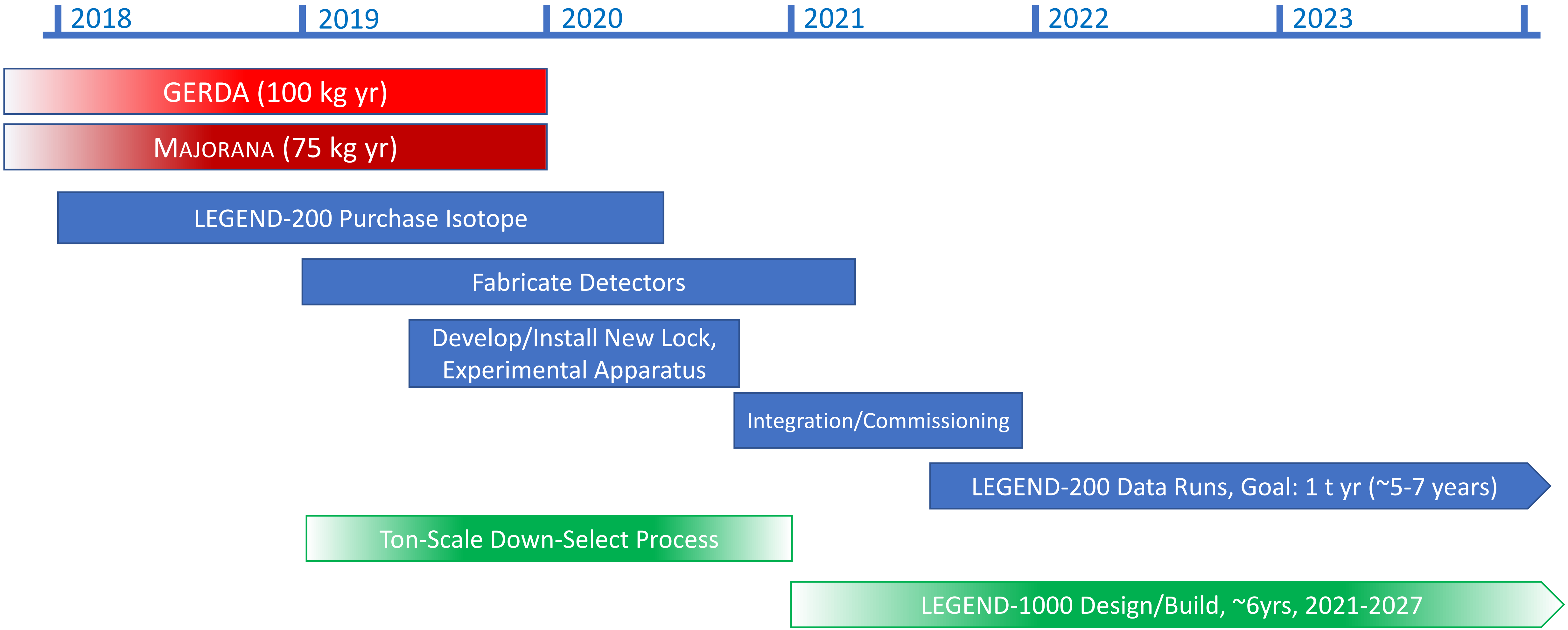
The background goal is projected to be met!

LEGEND-200: Current status

- In production mode for major construction this year
- Completed integrated DAQ tests with GERDA array January 2020
- GERDA hands over infrastructure to LEGEND this month!
- First immersion test with new detectors and electronics this month!



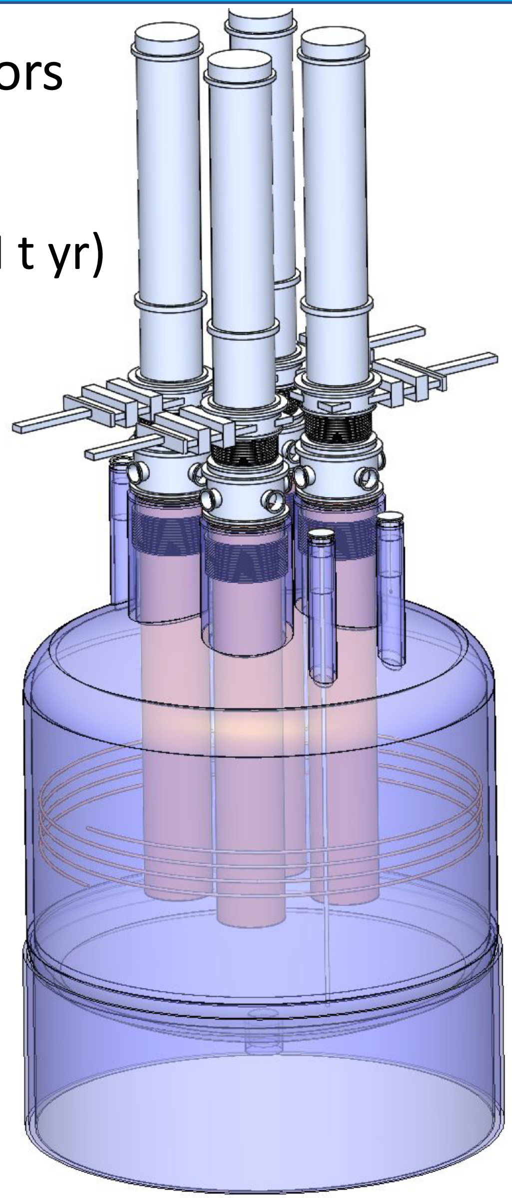
Schedule



Earliest, and optimistic, LEGEND-1000 Data Start 2025/6

LEGEND-1000

- Up to 1000 kg of ^{76}Ge-enriched detectors in individual payloads: 300-500 detectors
- Background goals for LEGEND-1000 20x lower than LEGEND-200: < 0.03 c/(FWHM t yr)
  - U/Th reduced by optimizing array spacing, minimizing inactive materials, larger detectors, better light collection, cleaner materials
  - ^{42}Ar eliminated by using Ar from underground sources near the detectors
- LEGEND-200 will help refine background model, provide better estimates to improve uncertainties
- Resolution ~2.5 keV FWHM@2039 keV
  - Already achieved in MAJORANA!

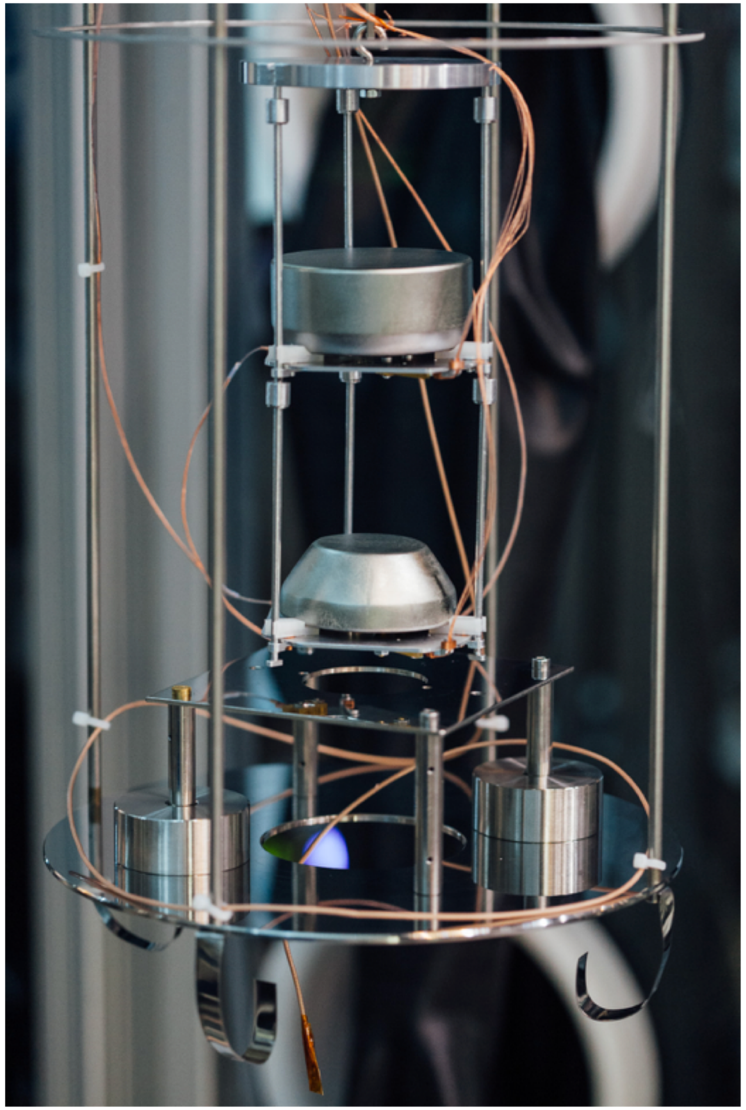


Summary

- LEGEND is combining the best of MAJORANA and GERDA in order to probe the entire inverted ordering region of interest for $0\nu\beta\beta$ in ^{76}Ge

- LEGEND-200 → begin operation in 2021
  - Funding secured
  - Enriched material and detector production ongoing
  - Background goal 5x lower than MAJORANA and GERDA
    - Expected to meet and exceed background goals!
  - Goal: **< 0.6 cts /(FWMH t y)** and **10^{27} yr** $T_{1/2}$ sensitivity

- LEGEND-1000 → up to 1000 kg of ^{76}Ge-enriched detectors in a phased approach
  - Goal: < **0.03 cts/(FWHM t yr)** and > $\mathbf{10^{28}}$ **yr** $T_{1/2}$ sensitivity



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