

LEGEND - Status and prospects

Christoph Wiesinger (Max-Planck-Institut für Kernphysik), EMMI Workshop, 23.09.2026

Neutrinoless double beta decay

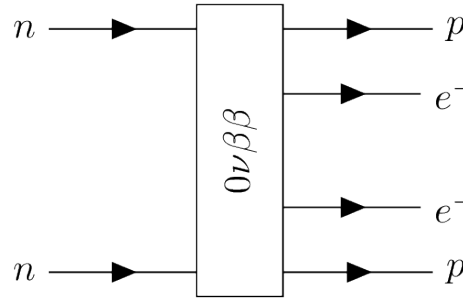
Observation of neutrinoless double beta decay would ..

1. .. prove **lepton number violation**,
various mechanisms possible
2. .. identify neutrino as its own antiparticle,
Majorana particle ($\nu \text{ --- } \times \text{ --- } \bar{\nu}$)

[Schechter, Valle, PRD 25 (1982) 2951]

3. .. determine **effective Majorana mass**

$$T_{1/2} \sim m_{bb}^{-2} \text{ where } m_{bb} = | \sum_i U_{ei}^2 m_i |$$



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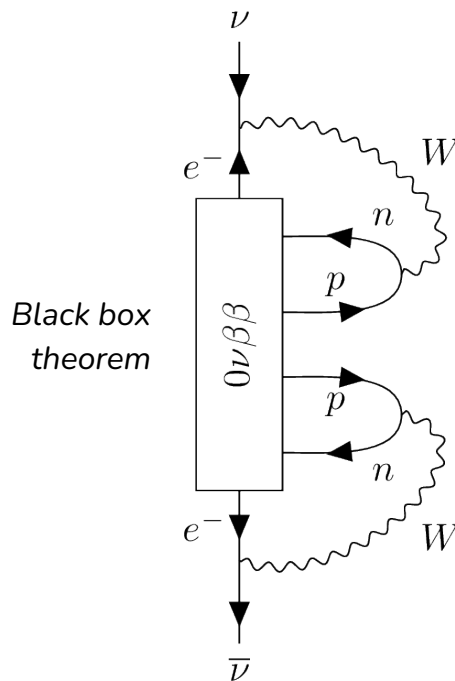
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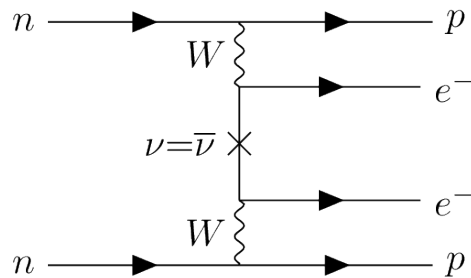
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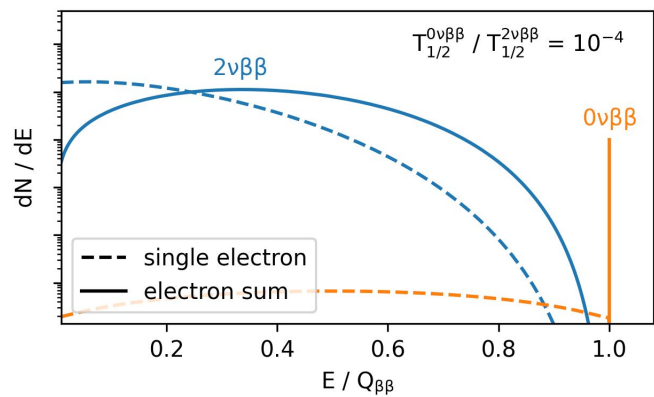


Light **Majorana neutrino exchange**,
Mass mechanism

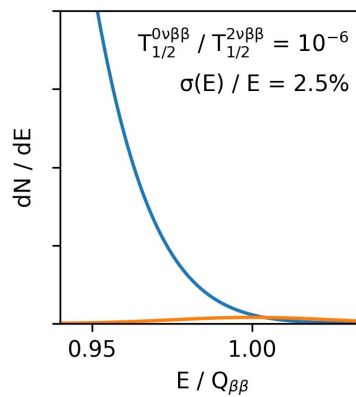
Decay signature

Unaccompanied emission of **two electrons** from double beta isotope (e.g. ^{76}Ge , ^{100}Mo , ^{130}Te , ^{136}Xe)

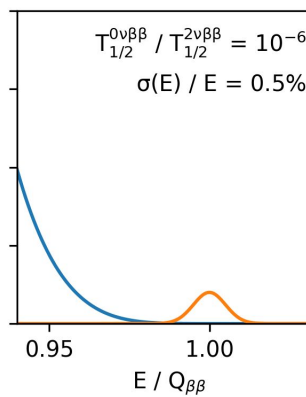
- Two-electron **topology** *Necessary*
- **Daughter isotope** production *Necessary*
- **Mono-energetic** electron sum *Sufficient*



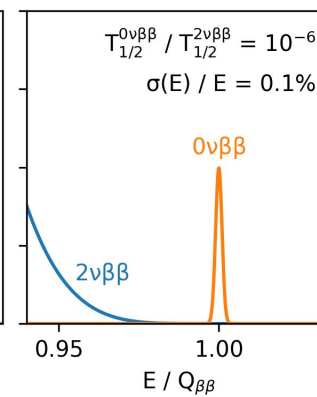
Scintillator
detectors



Time-projection
chambers



Cryogenic or
semiconductor
detectors



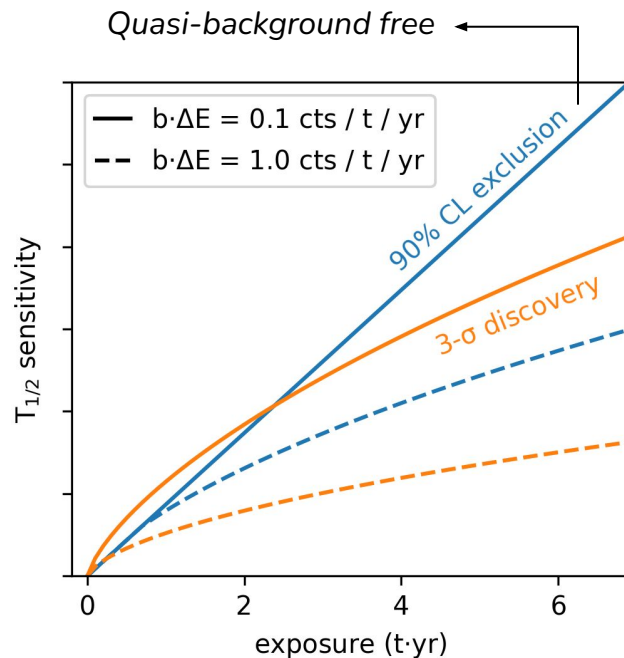
Background importance

- Signal counts $n_s \sim m \cdot t / T_{1/2}$
- Background counts $n_b \sim b \cdot \Delta E \cdot m \cdot t$
 ↳ **Background index** in e.g.
 counts / keV / kg / yr = cpkky

Sensitivity **scaling**:

- Background-limited** ($n_s \sim n_b^{1/2}$): $T_{1/2} \sim (m \cdot t)^{1/2}$
- Background-free** ($n_b \ll 1$): $T_{1/2} \sim m \cdot t$

Only a background-free experiment makes efficient use of the precious isotope material

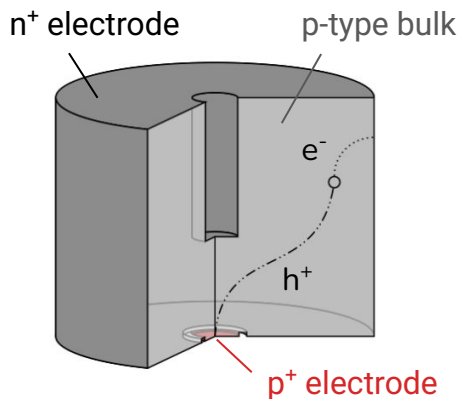


LEGEND collaboration

- Large Enriched Germanium Experiment for Neutrinoless double beta Decay (LEGEND)
- **> 300 scientists and engineering** from 11 countries across 3 continents



Experimental approach



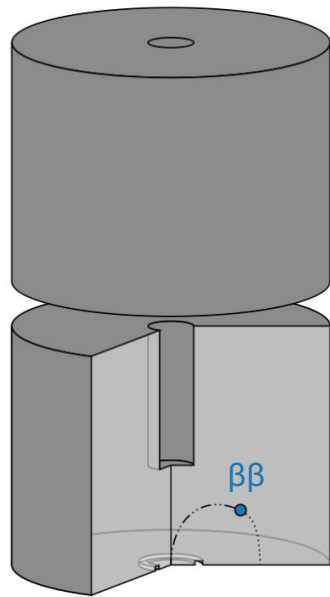
Inverted coaxial (IC) detector,
small capacitance, favourable
field geometry, large mass

[Cooper et al., NIM A 665 (2011) 25-32]

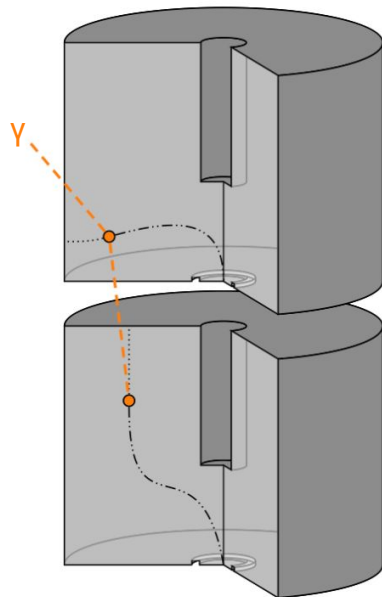
High-purity Germanium (HPGe) detectors made from enriched Ge (> 90% ⁷⁶Ge)

- **Source = detector** -> high detection efficiency
- High-purity material -> **no intrinsic background**
[Agostini et al., Astropart.Phys. 91 (2017) 15-21]
- Semiconductor -> excellent energy resolution,
< 0.1% at Q_{bb} = 2039 keV
- High stopping power -> betas absorbed within **O(1) mm**

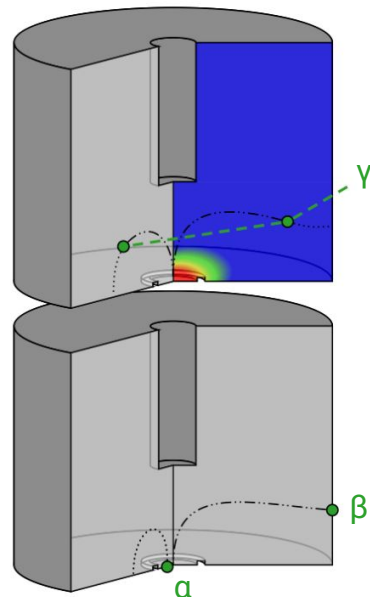
Topology discrimination



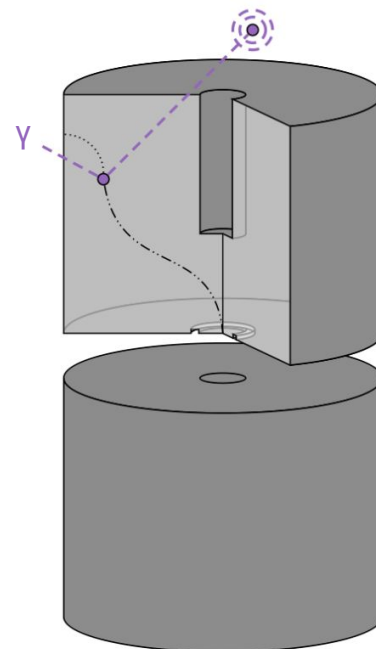
Single-site event



Multi-detector hit



Multi-site / surface events



LAr coincidence

Phased approach

LEGEND-200

- Up to 200 kg of enriched HPGe detectors at 10^{-4} cpkky
- Upgraded GERDA infrastructure at LNGS Hall A

LEGEND-1000

- 1000 kg of enriched HPGe detectors at 10^{-5} cpkky
- New infrastructure at LNGS Hall C

The image is a 3D architectural rendering of the LEGEND detector infrastructure at LNGS. It shows a large, dark, cylindrical structure representing the detector cryostat. A cutaway view reveals the internal components, including the HPGe detectors and the support structure. A small inset image shows a map of Germany with various locations marked, and a list of participating institutions. The text 'Forschungsinfrastruktur (FIS) Priorisierungsverfahren' is visible on the map. The rendering is set against a white background with a grid pattern.

Christoph Wiesinger (MPIK)

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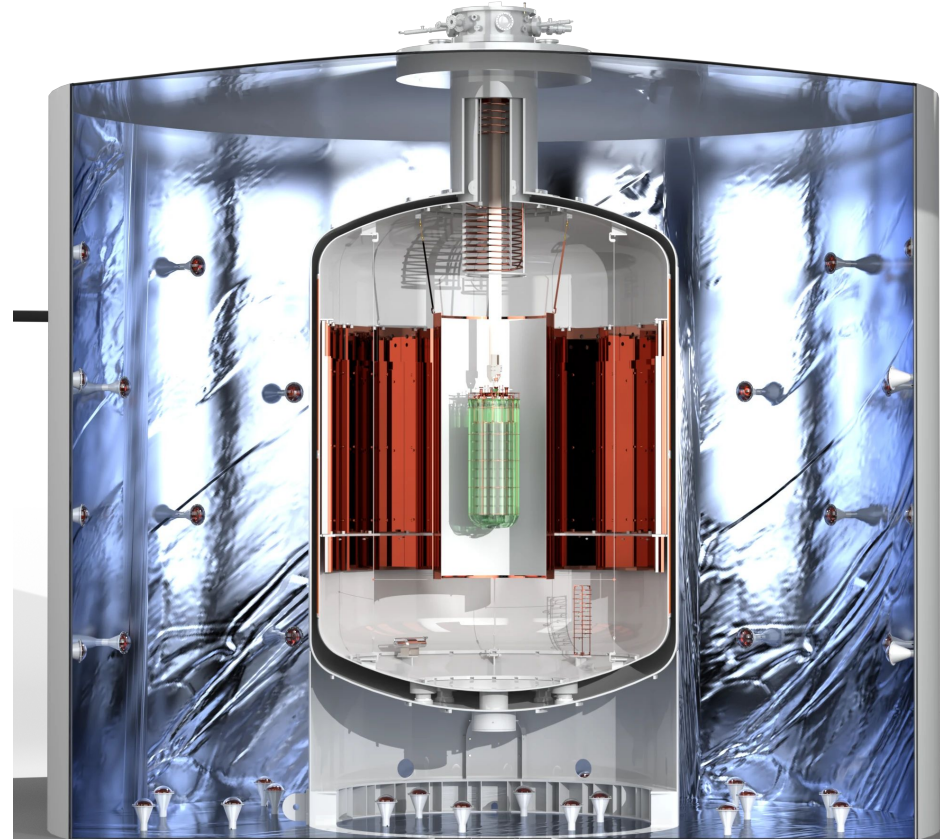
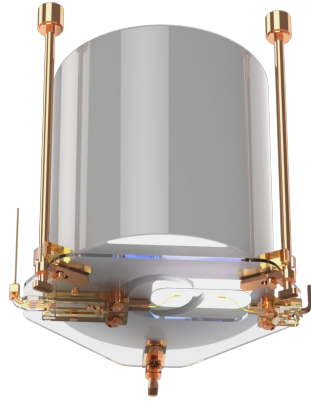
LEGEND-1000

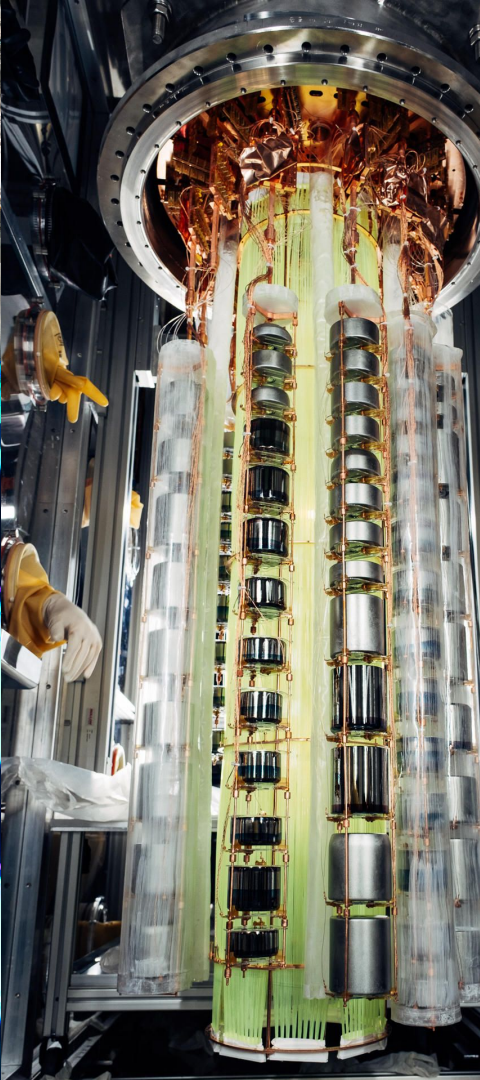
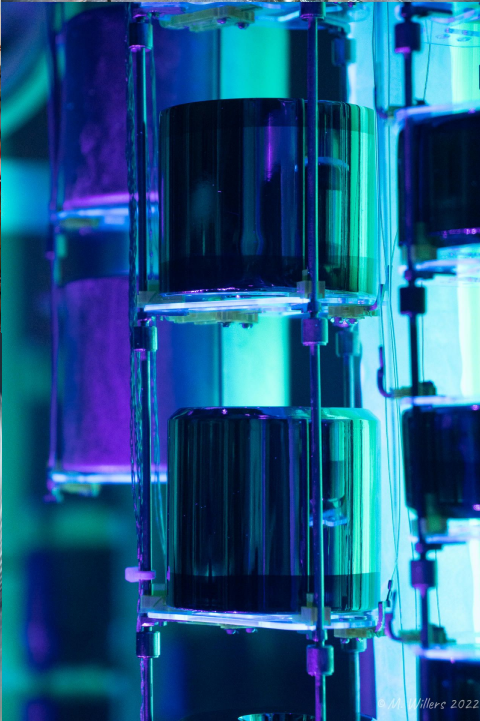
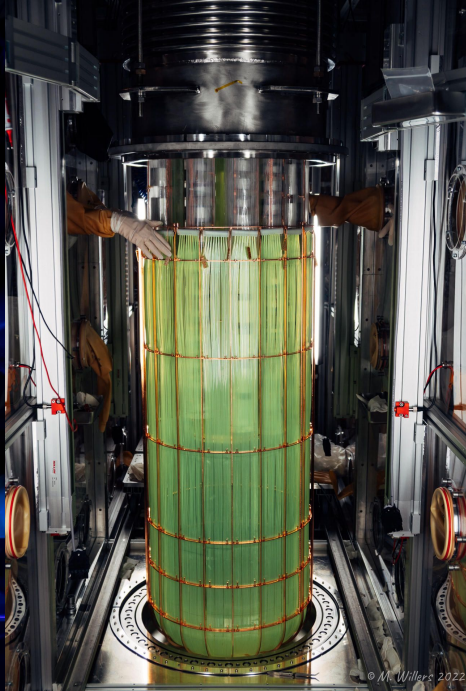
 - 1000 kg of enriched HPGe detectors at 10^{-5} cpkky
 - New infrastructure at LNGS Hall C
- 
- Christoph Wiesinger (MPIK)



LEGEND-200

- Array with up to **14 HPGe detector strings**, electroformed copper, PEN as scintillating structural material, **light read-out** with WLS-fibers coupled to SiPM
- **Nested active shield**, 90 t **atmospheric LAr** in 600 t **water**, HPGe detectors in LAr-scintillation detector in water-Cherenkov detector
- 1400 m.w.e. of **rock overburden**





Status

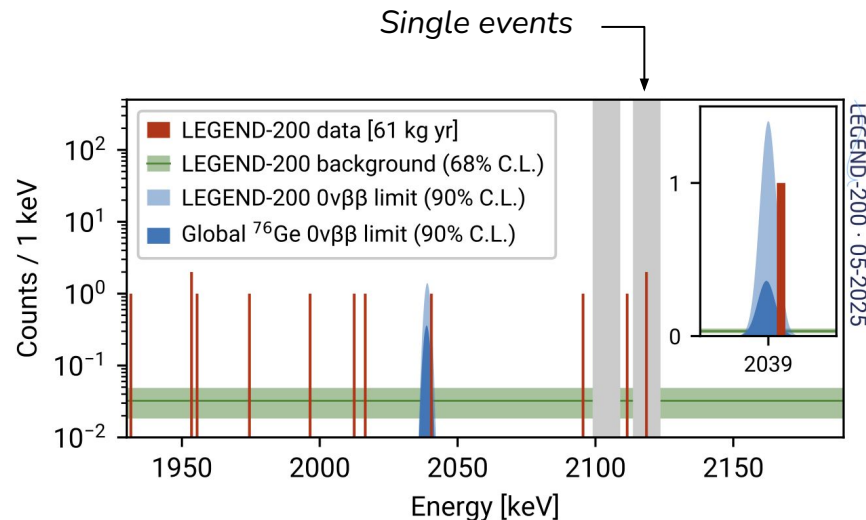
- **First physics result**, 140 kg from March 2023 to February 2024

61 kg yr at $5^{+3}_{-2} \cdot 10^{-4}$ cpkky

- Combined analysis (GERDA + MJD + LEGEND-200)
[Acharya et al., PRL 136 (2026) 2, 022701]

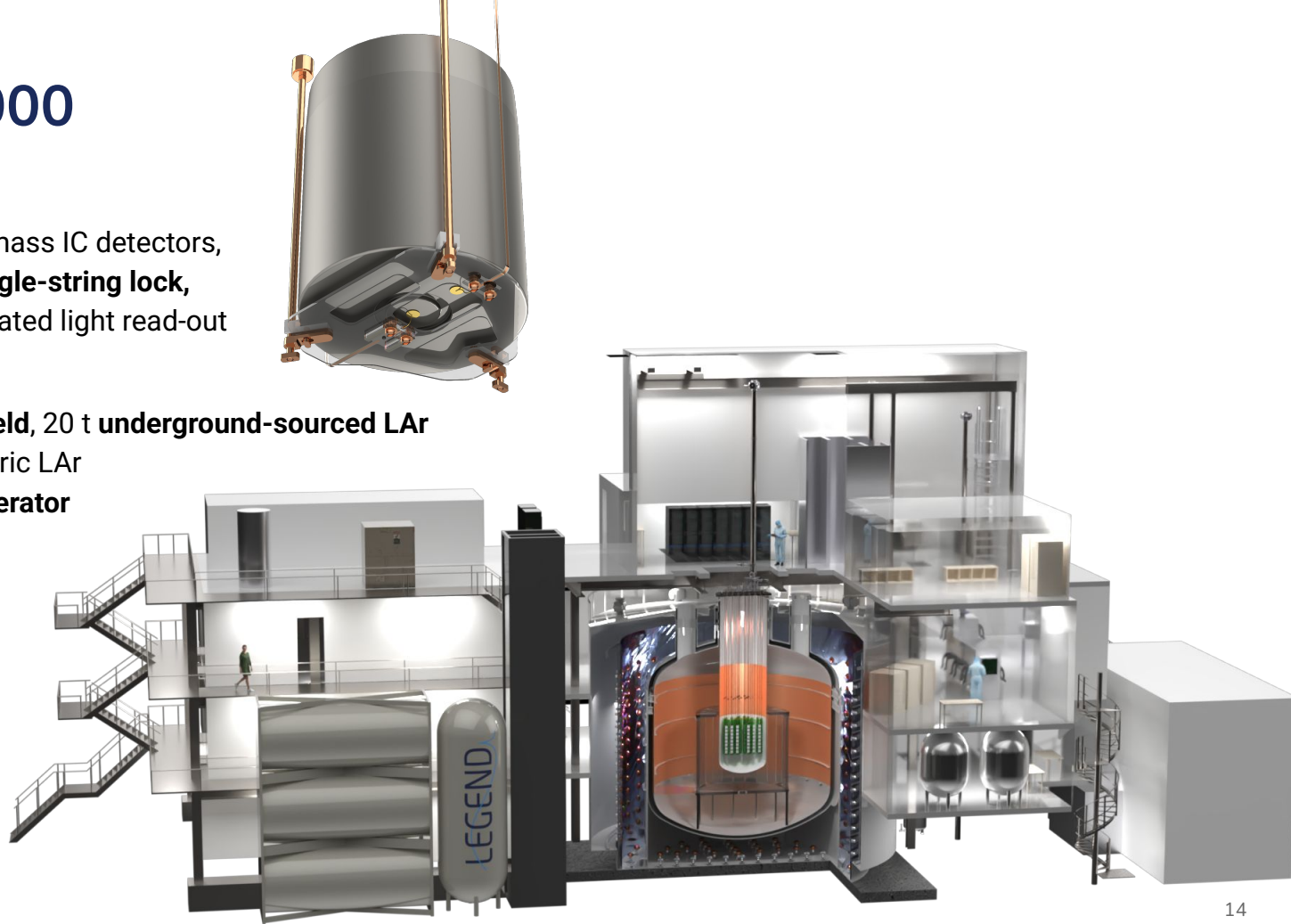
$T_{1/2} > 1.9 \cdot 10^{26}$ yr $\rightarrow m_{bb} < [75, 200]$ meV (90% CL)
> $2.8 \cdot 10^{26}$ yr (90% CL, sensitivity)

- Array maintenance, conversion of small-mass and under-performing detectors into **large-mass IC detectors**, successful **reduction of gamma background**
- Redeployment in July 2025, **data taking ongoing**

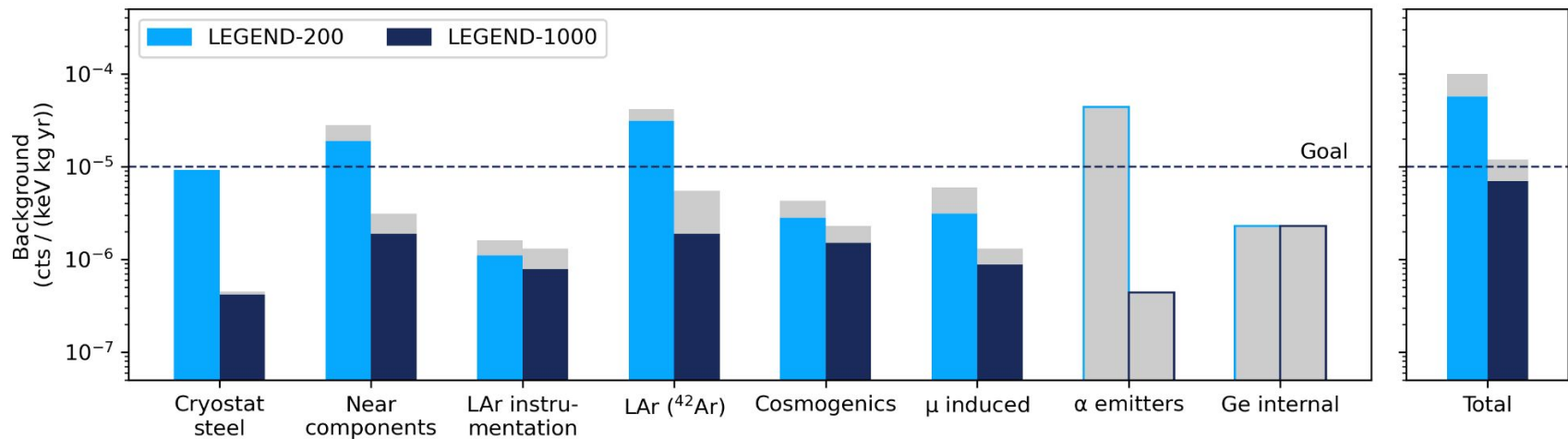


LEGEND-1000

- **1000 kg** of large-mass IC detectors, **ASIC** read-out, **single-string lock**, strings with integrated light read-out
- **Nested active shield**, 20 t **underground-sourced LAr** in 250 t atmospheric LAr with **neutron moderator** in 700 t water

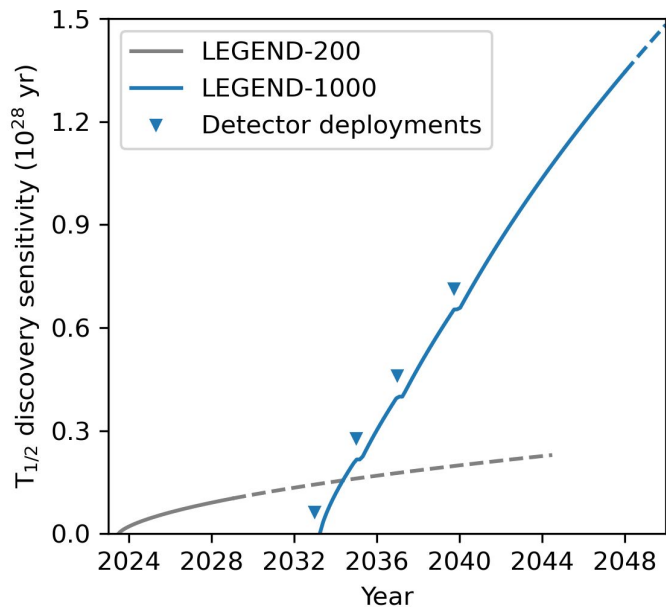


Background projection



- **Background reduction** on all fronts, large-mass detector (less auxiliaries, better surface-to-volume), underground-sourced argon (^{42}Ar mitigation), reduction of non-active auxiliaries, electronics, ..
- Expect to meet background goal

Prospects



- Exploration up to and **beyond** 10^{28} yr, projected sensitivity

[Abgrall et al., arXiv:2107.11462, pCDR]

$$T_{1/2} = 1.3 \cdot 10^{28} \text{ yr (3-}\sigma) \rightarrow m_{bb} = [9, 21] \text{ meV}$$

Discovery $\xrightarrow{\quad}$ $\uparrow$

- Outperform LEGEND-200 early after first deployment

Conclusions

- **First result** of LEGEND-200 (+ GERDA + MJD) provides best constraint for ^{76}Ge

[Acharya et al., PRL 136 (2026) 2, 022701]

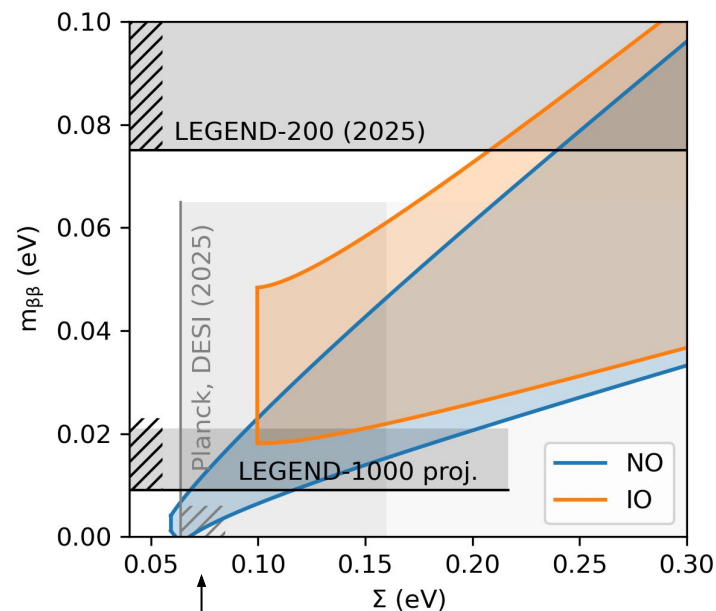
$$T_{1/2} > 1.9 \cdot 10^{26} \text{ yr (90\% CL)}$$

- **LEGEND-200 data taking ongoing**, probing unexplored parameter space in next years

- **LEGEND-1000 in preparation**, projected sensitivity

[Abgrall et al., arXiv:2107.11462, pCDR]

$$T_{1/2} > 1.3 \cdot 10^{28} \text{ yr (3-}\sigma\text{)}$$



Cosmological model
(Λ CDM)

Backup