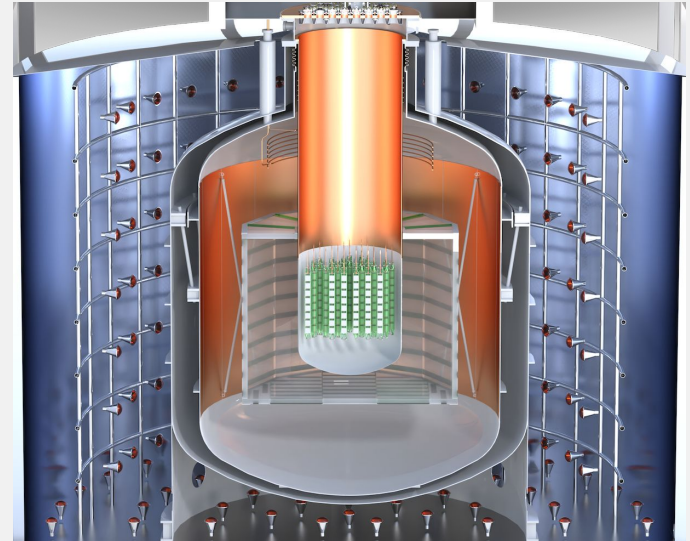


Development of a Liquid Argon Purity Monitor Utilizing Electron Drift

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20 October 2026

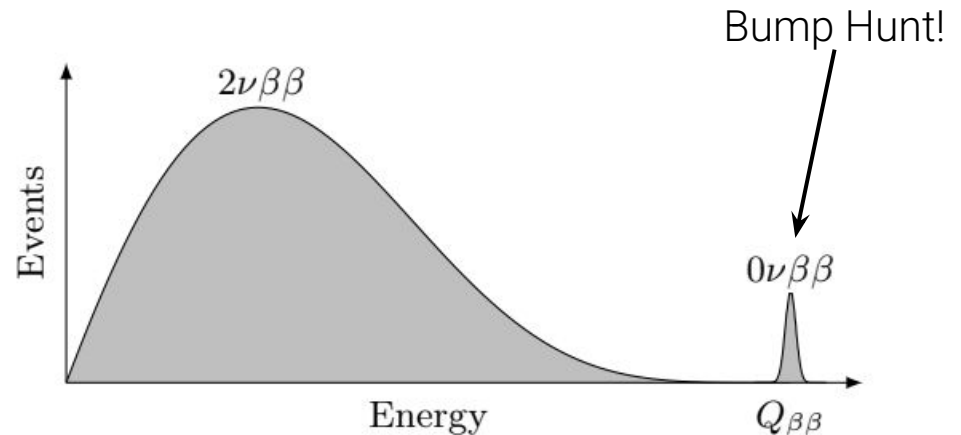
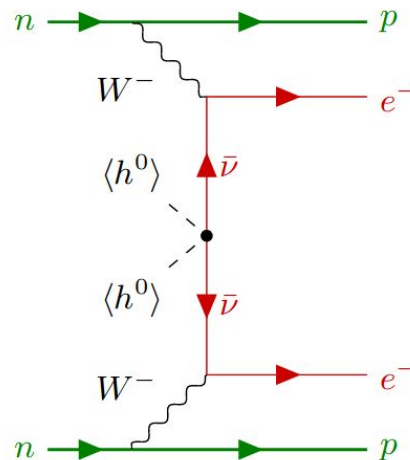
LEGEND Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay



$0\nu\beta\beta$ Decay

- A select few nuclei can undergo two simultaneous beta decays
 - Can only observe $2\nu\beta\beta$ decay in nuclei where single beta decay is energetically forbidden, or highly suppressed
- $0\nu\beta\beta$ may also occur in these nuclei, where no neutrinos are emitted
 - Violates Lepton Number conservation and B - L conservation
 - Demonstrates non-zero Majorana Mass

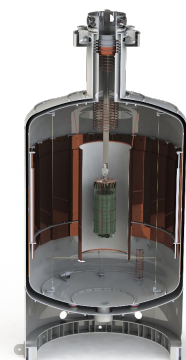
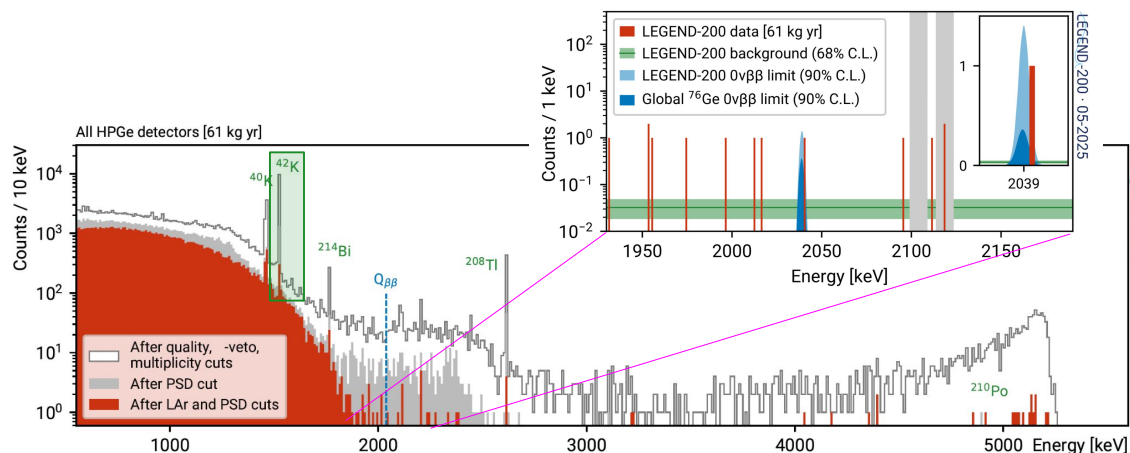
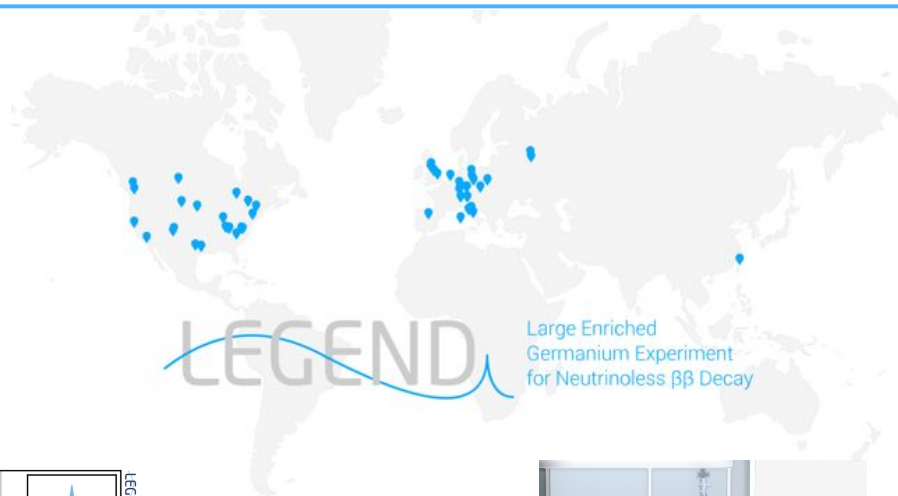
Proposed
Mechanism for
 $0\nu\beta\beta$



The LEGEND Collaboration

The LEGEND Collaboration hopes to improve the half life discovery sensitivity for $0\nu\beta\beta$ in ^{76}Ge to 10^{28} yr in a staged experimental program

Construct detectors out of enriched Ge – Our detectors are our sources!



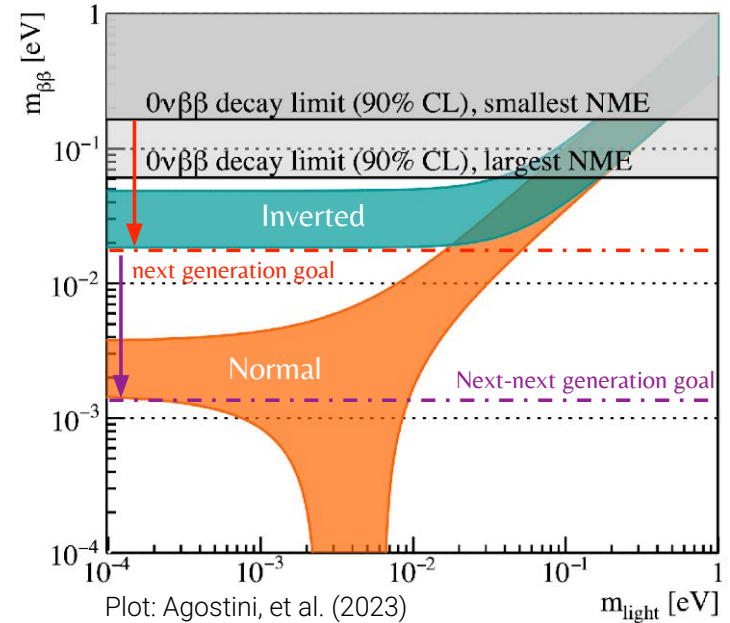
LEGEND-200



LEGEND-1000

Current & Next Generation

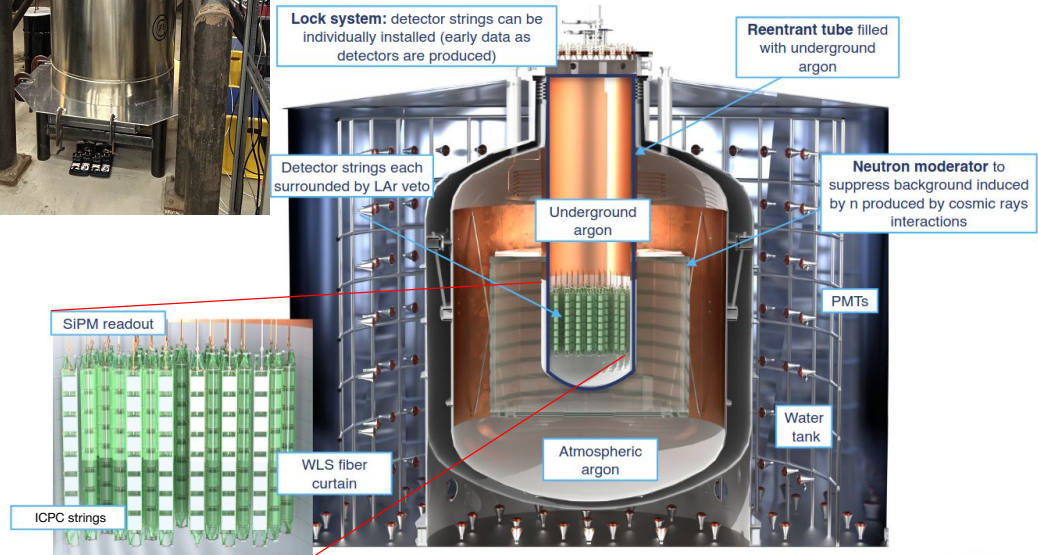
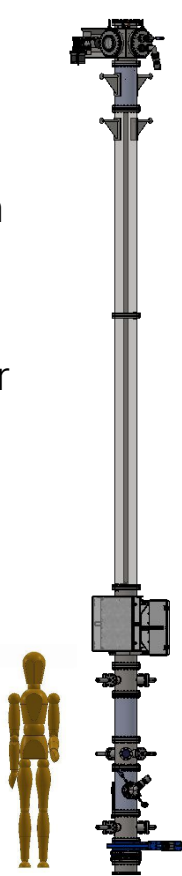
- LEGEND-200: Up to 200 kg of Germanium enriched to >90% ^{76}Ge deployed in a large LAr cryostat at LNGS
 - Sets current half life limit at $T_{1/2} > 1.9 \times 10^{26}$ yr
- LEGEND-1000: 1-ton of Germanium detectors enriched to >90% ^{76}Ge deployed in new experimental infrastructure at LNGS; data taking projected to begin in early 2030s
 - Hopes to cover inverted ordering (IO) parameter space



LEGEND-1000 - The Next Generation

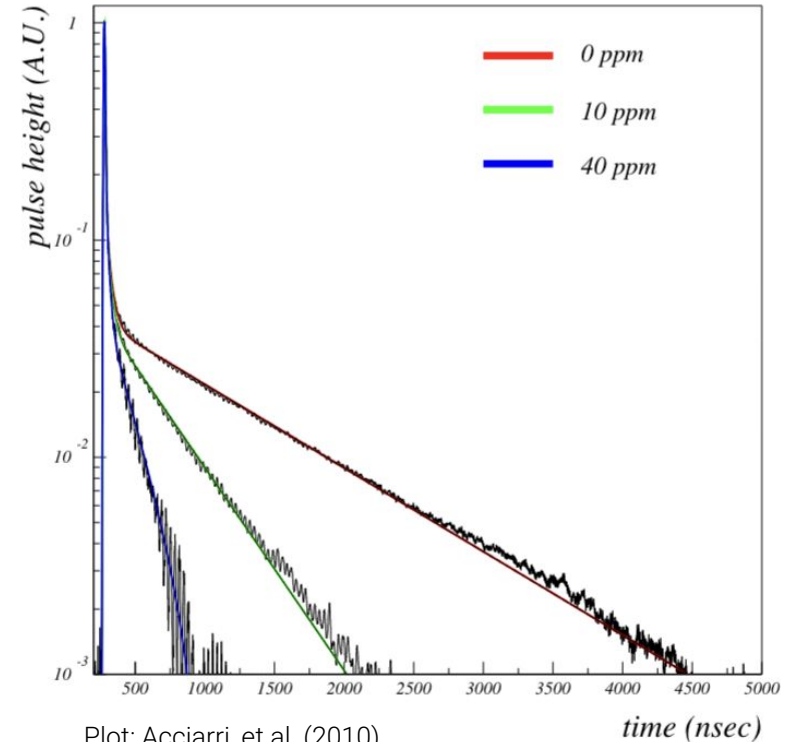
Notable Upgrades from L200

- More Germanium => Ton Scale
- Larger Detectors, uniform geometry
- Inner Volume of Underground Sourced LAr
- **Detector Deployment System for Single String deployment**
 - Prototyping underway here at UW

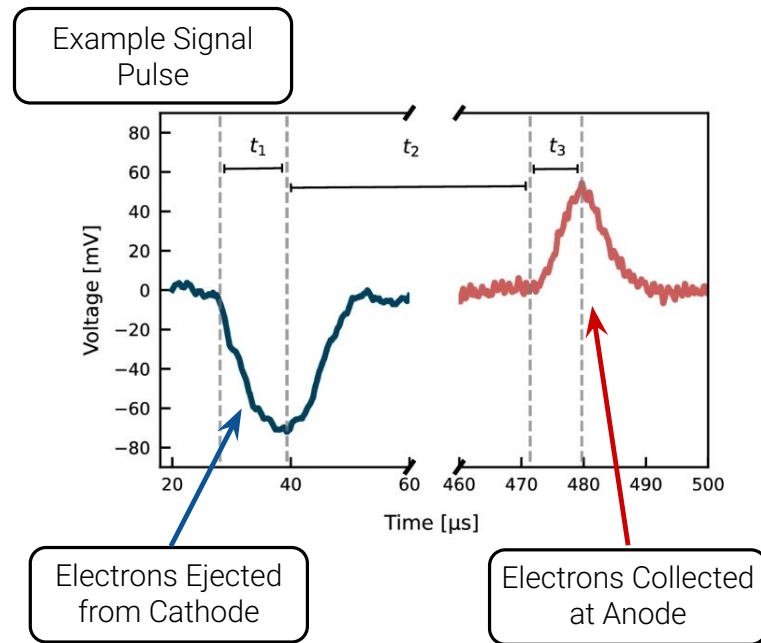
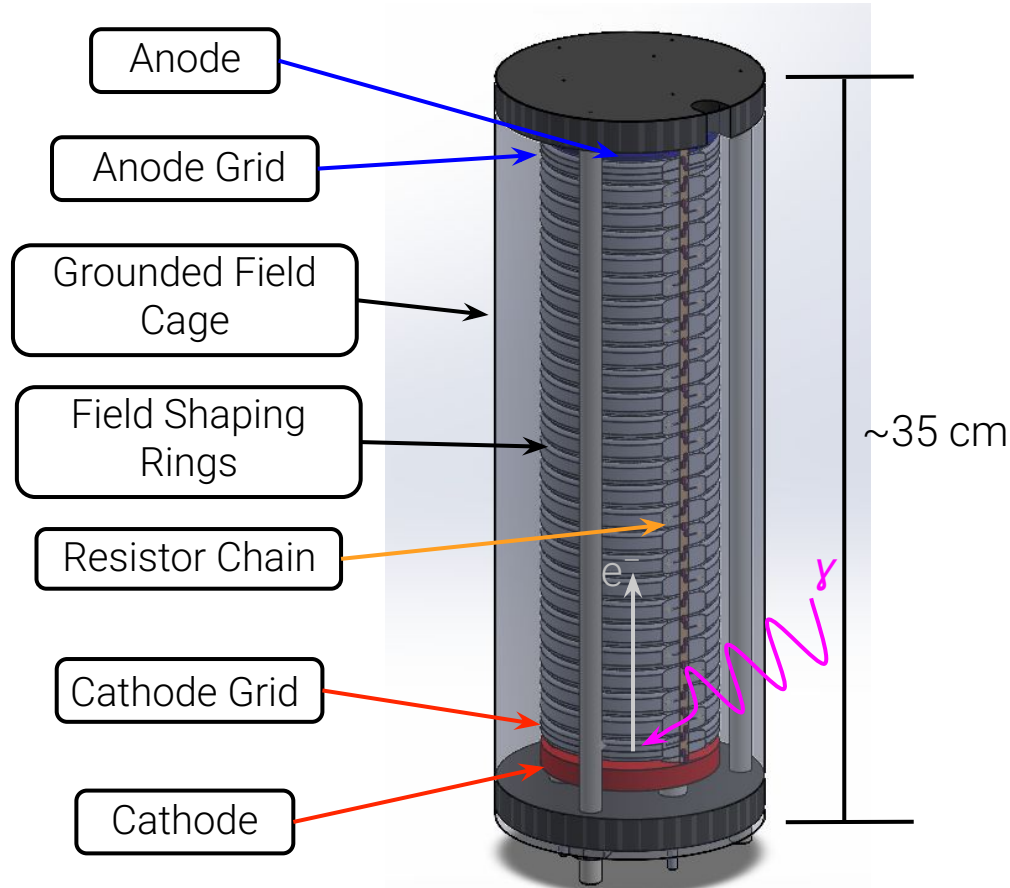


Argon Purity is Important

- LEGEND uses liquid argon scintillator for background rejection
- Lock specifications require <0.5 ppb contamination in argon
 - Contaminants reduce argon light yield
- Reduced light yield $\rightarrow$ worse background rejection



The Liquid Argon Purity Monitor



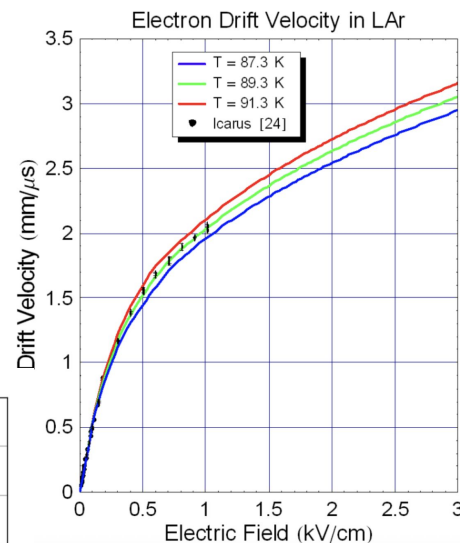
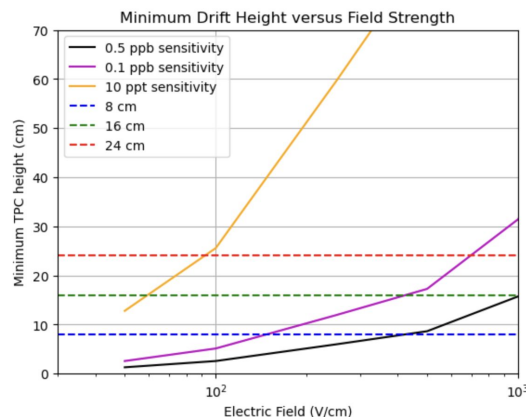
Drift Volume Dimensions Depend on Argon Properties

- Will deploy in 500L of liquid argon
 - Limit of 0.46 ppb
 - Translates to $\tau \sim 0.5$ ms
 - Assume can read $R_Q \sim 0.9$
- Height set by drift velocity at field value
 - Must drift long enough to see loss of electrons at anode
- Settled on height of 30 cm, internal radius of 2 cm, operated at 50 - 100 V/cm

$$\tau = \frac{1}{n \cdot k}$$

n = impurity density

k = e^- attachment rate



$$h_{\min} = v_d \cdot \tau \cdot \ln(R_Q)$$

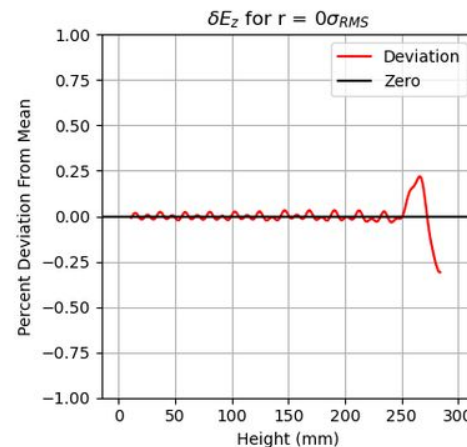
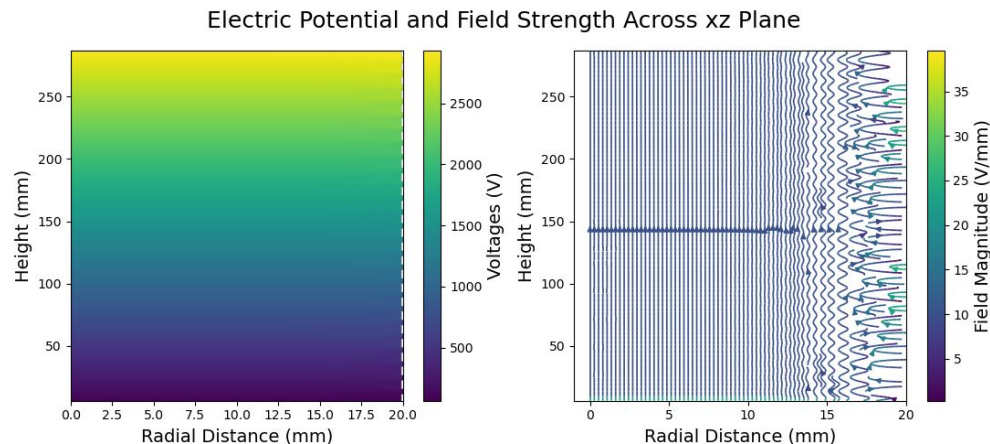
v_d = drift vel.

τ = electron lifetime

R_Q = ratio of collected charge

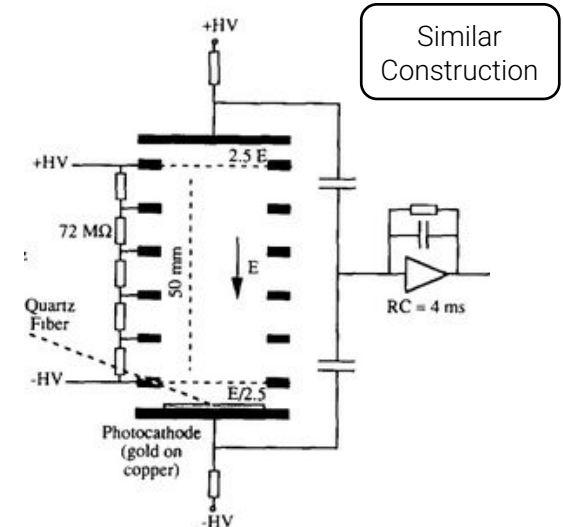
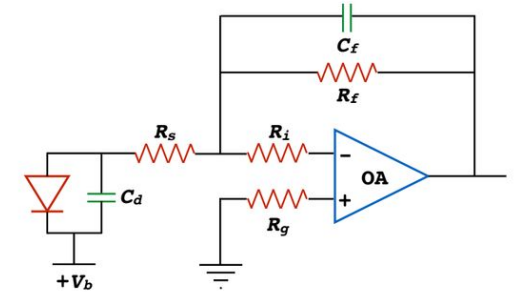
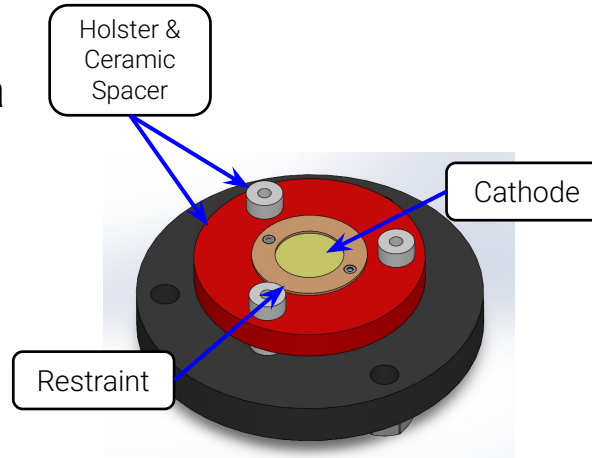
Simulations to Produce Uniform Fields

- Several configurations simulated using Simlon
 - Varied number of rings, ring spacing, ring thickness, ring radii, etc.
- Desire uniform field at center of drift volume
 - Small Radial Field
 - Constant Longitudinal Field
- Result: 26, 1 cm thick rings, 1mm apart, 2 cm inner radius
 - Reach <0.1% Uniformity on axis



Optical chain & Electronics

- Cathode comprised of gold plated fused silica wafer
- Photoelectrons produced via exterior Xenon flashlamp
- Convert current to voltage using Transimpedance Amplifier (TIA)
 - Must operate under cryogenic temperatures



Plot: Bettini, et al. (1991)

Status and Plans

- Reaching Final Stages of design
 - Deciding on final specifications for electronic components, field grids
 - Sourcing Optical components for optimal UV transmission to Cathode
- Begin with test runs in vacuum before moving to testing in Argon
- Long term Deployment in cryostat for purity monitoring
- Future Plans to operate in Solid Argon to measure properties
 - See *Study of Scintillation Properties of Solid Argon* by Claudio Savarese

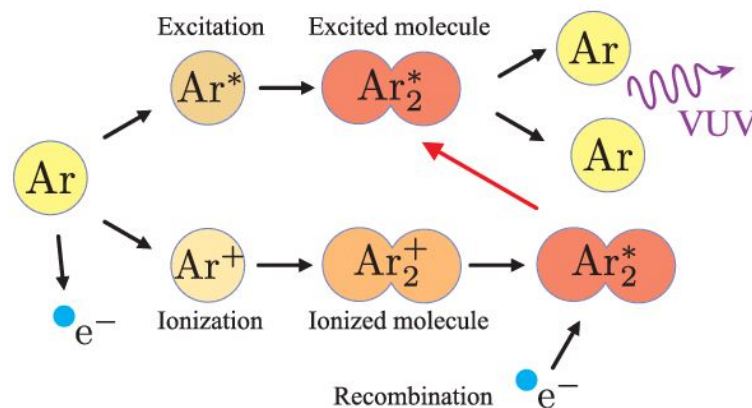


- ¹ LEGEND collaboration, H. Acharya, *et al.*, First results on the search for lepton number violating neutrinoless double- β decay with the LEGEND-200 experiment, Phys. Rev. Lett. 136 (2026) 022701. arXiv:2505.10440 [hep-ex], <https://doi.org/10.1103/PhysRevLett.136.022701>.
- ² M. Agostini, *et al.*, Toward the discovery of matter creation with neutrinoless $\beta\beta$ decay, Rev. Mod. Phys. 95 (2023) 025002. arXiv:2202.01787 [INSPIRE].
- ³ WArP Collaboration, Acciarri R. *et al.* Effects of Nitrogen contamination in liquid Argon, JINST 5 (2010) P06003 (arXiv:0804.1217)
- ⁴ A. Bettini, *et al.*, A study of the factors affecting the electron lifetime in ultrapure liquid Argon, Nucl. Instr. And Meth. A 305 (1991) 177.

Backup slides

Argon Scintillation

- Liquid Argon used as scintillator to block background and reject events originating from outside the detectors.
 - Short lifetime singlet excimer state, long lifetime triplet excimer state
- Contamination reduces triplet lifetime through quenching
 - Electrons capture on impurity, preventing scintillation
 - Contamination is bad for light collection, makes background harder to distinguish from possible signal
- **Lock System needs to keep Argon pure**



Drift Volume Radius

Radius set by transverse spread

Even at high fields, spread on order millimeters, not a large concern

Wider radii lead to more uniform fields at the center, and is more practical

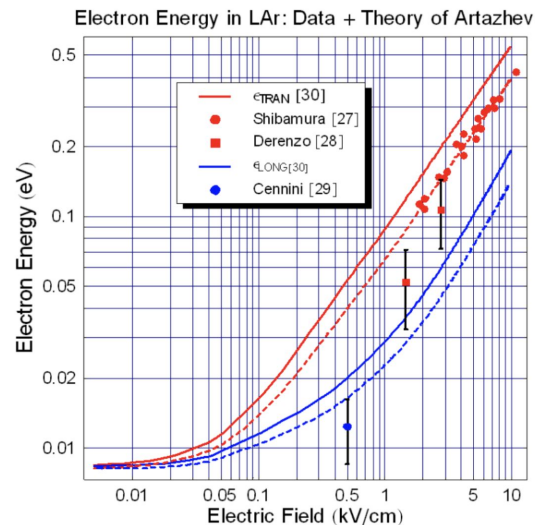
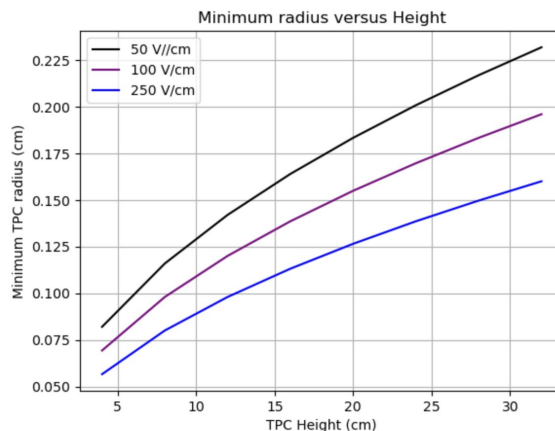
$$\sigma_T = \sqrt{\frac{2\epsilon_T h}{E}}$$

σ_T = Transverse Spread

ϵ_T = Transverse Energy

h = drift height

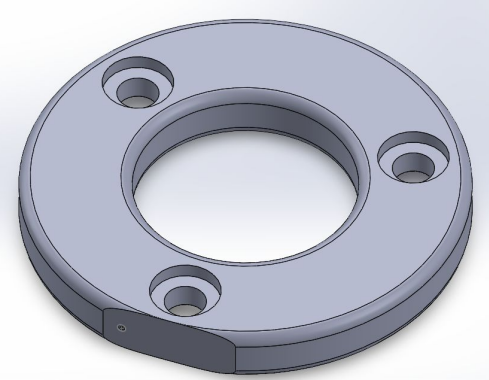
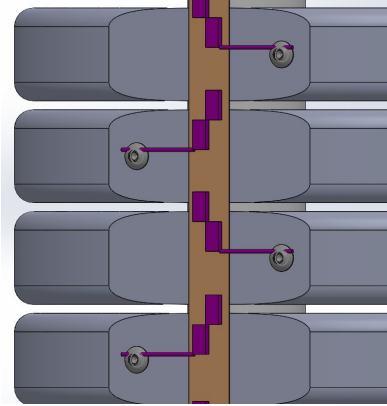
E = Electric Field



Other Design Considerations

Biasing components

- Chain of resistors to apply even voltage gradient to field rings
 - Kapton PCB with thick film resistors and leads to attach to rings



Stacking Rings

- Grooves cut into rings to hold ceramic washers for spacing
- Through holes for stainless steel rod to aid in alignment

