Background Rejection in Ge $0\nu\beta\beta$ Experiments

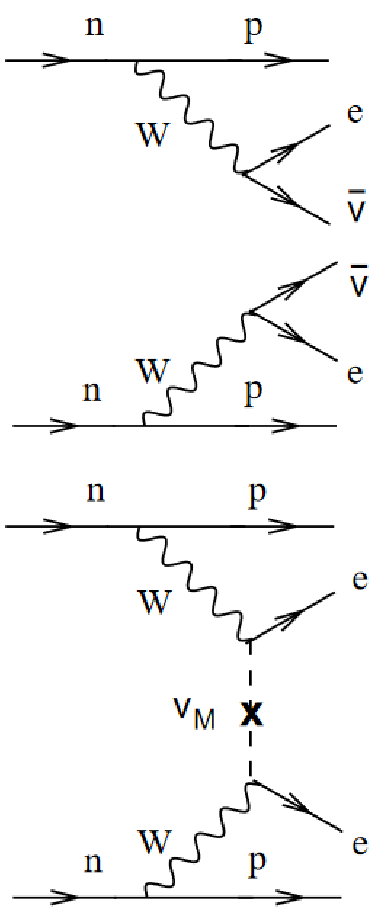
Ryan Gibbons

Physics 290E

April 14, 2021

Double Beta Decay

Symmetry Magazine



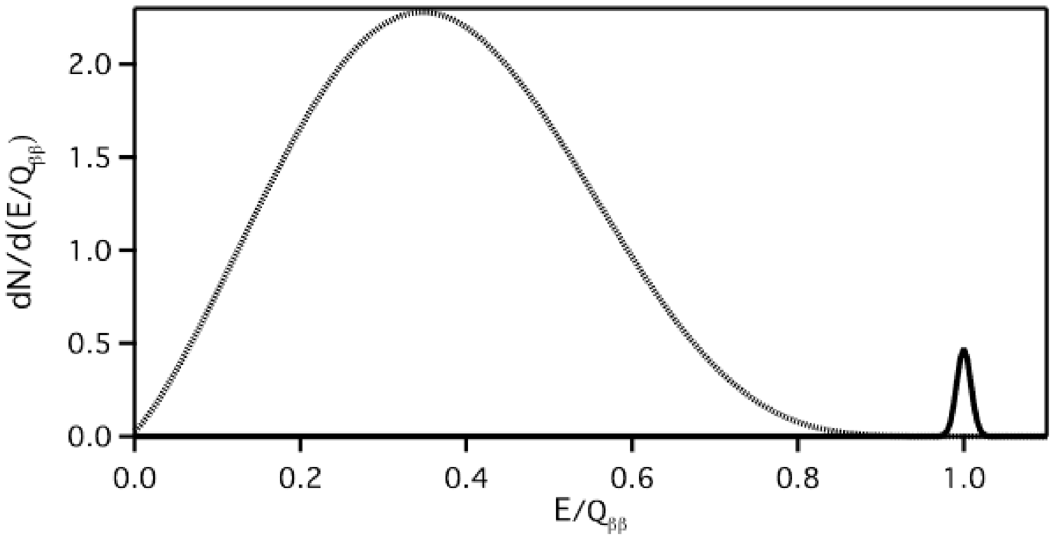
- ββ (2νββ)
  - $2n \rightarrow 2p + 2e^- + 2\bar{\nu}$
  - Measured in ~ 30 isotopes
- 0νββ
  - $2n \rightarrow 2p + 2e^-$
  - Theorized process that requires Majorana neutrinos
  - i.e., no distinction between $\bar{\nu}$ and ν
  - ν mass mechanism not understood → see-saw mechanism?
  - Matter-antimatter asymmetry → Leptogenesis?

Detecting 0vββ

- 0vββ signal: small peak at $Q_{\beta\beta}$
  - v's energy transferred to electrons

- So pick a source and wait?
  - Not so fast!
  - ββ $T_{1/2}$ ~ 10^{21} years
  - 0vββ $T_{1/2}$ ~ 10^{28} years?

- Expected signal size: ~ 1 counts/(t yr)
  - Requires near-zero background!



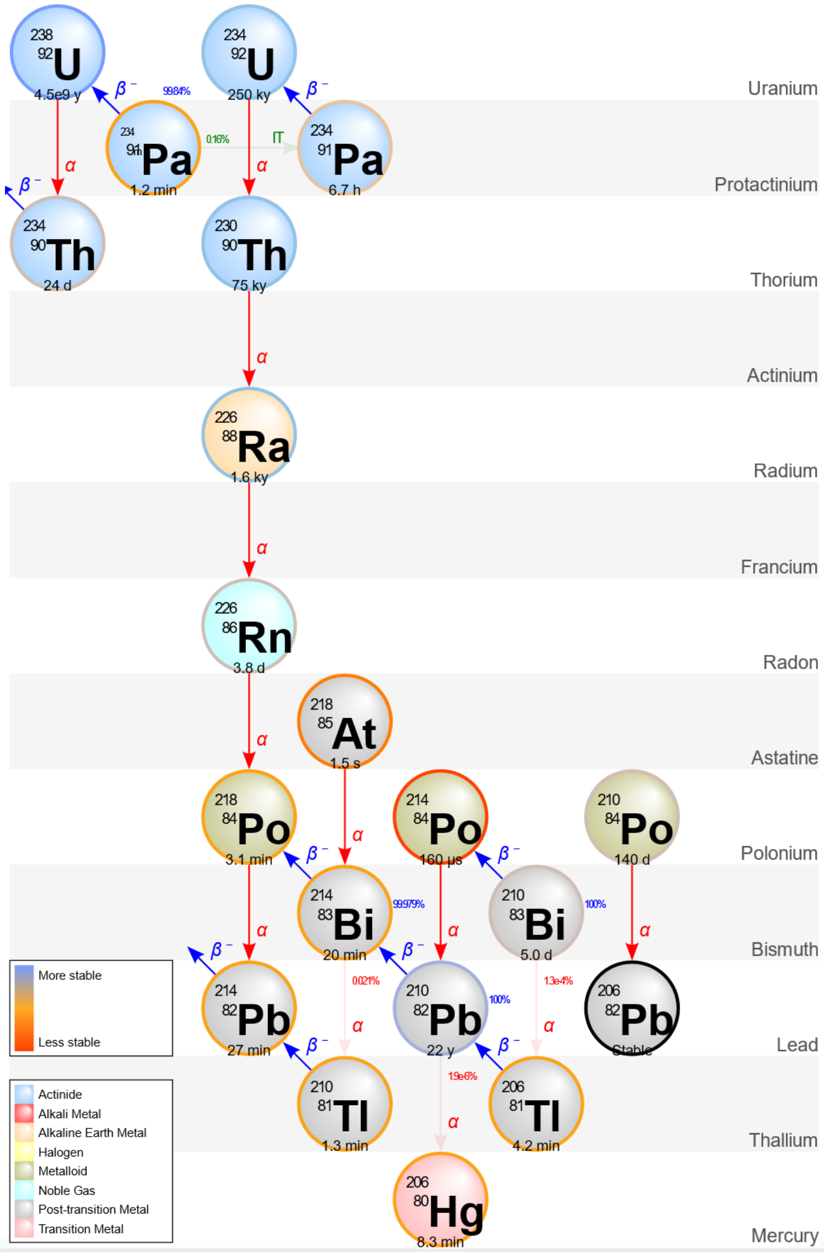
Basic Experimental Design

- Typically use large source: ~ 100 kg - 1 t
- Underground experiment
  - Block cosmic rays
- Radiopure materials
  - Minimize exposure and volume
- Efficient active background rejection

MAJORANA Demonstrator

Background Sources

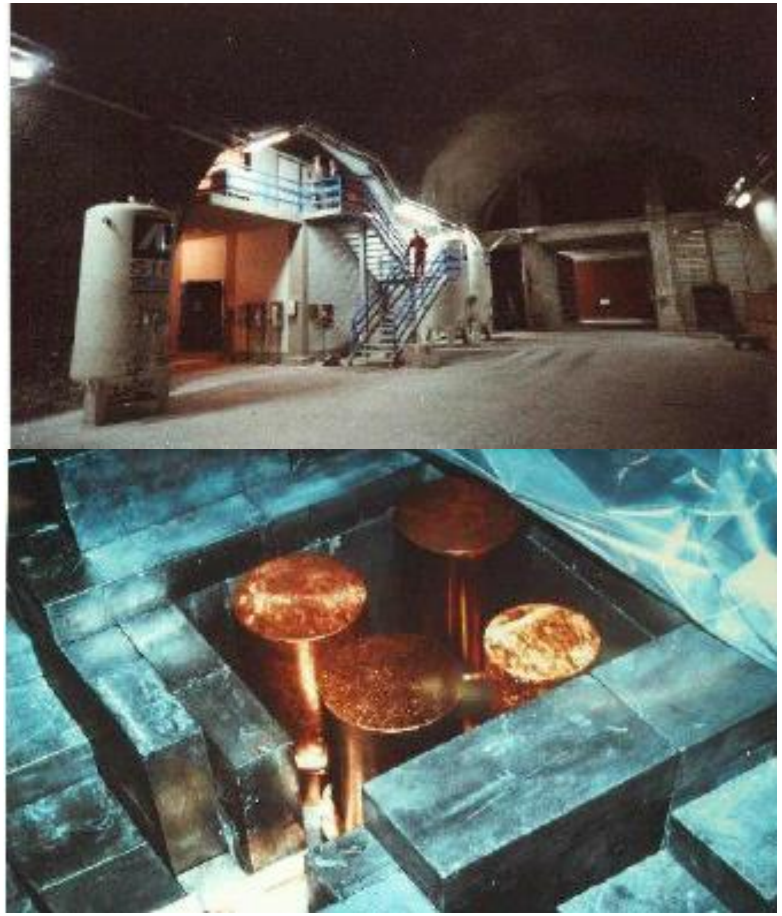
- Long-lived chains
  - ^{238}U, ^{232}Th
- Above ground activation of materials
  - e.g., ^{60}Co
- Cosmic muons



Ge Based Experiments

- Use Ge detector enriched with ^{76}Ge source
  - ~ keV resolution in ROI, ~2 MeV (~0.1%)
  - Easy to create high-purity detectors
  - Ge detectors are well studied

- Experiments:
  - Past: Heidelberg-Moscow, IGEX
  - Recent: GERDA, MAJORANA
  - Upcoming: LEGEND



Heidelberg-Moscow
(disputed result nullified)

GERDA

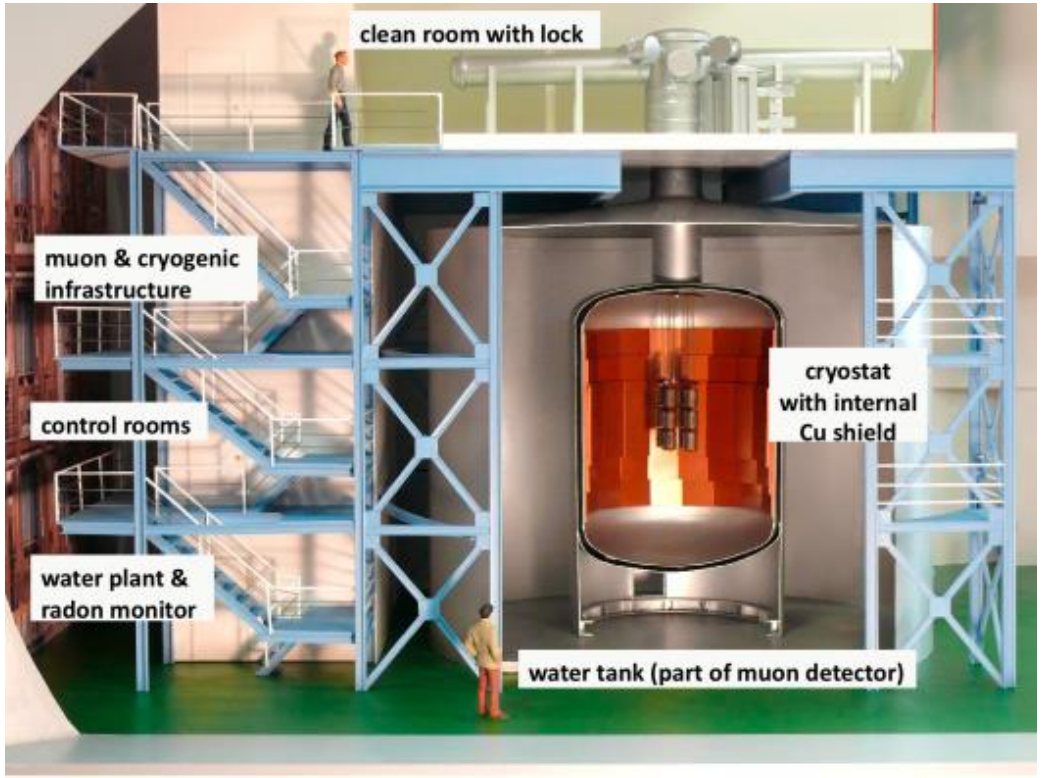
- **Ger**manium **D**etector **A**rray

- 2011-2019 at LNGS

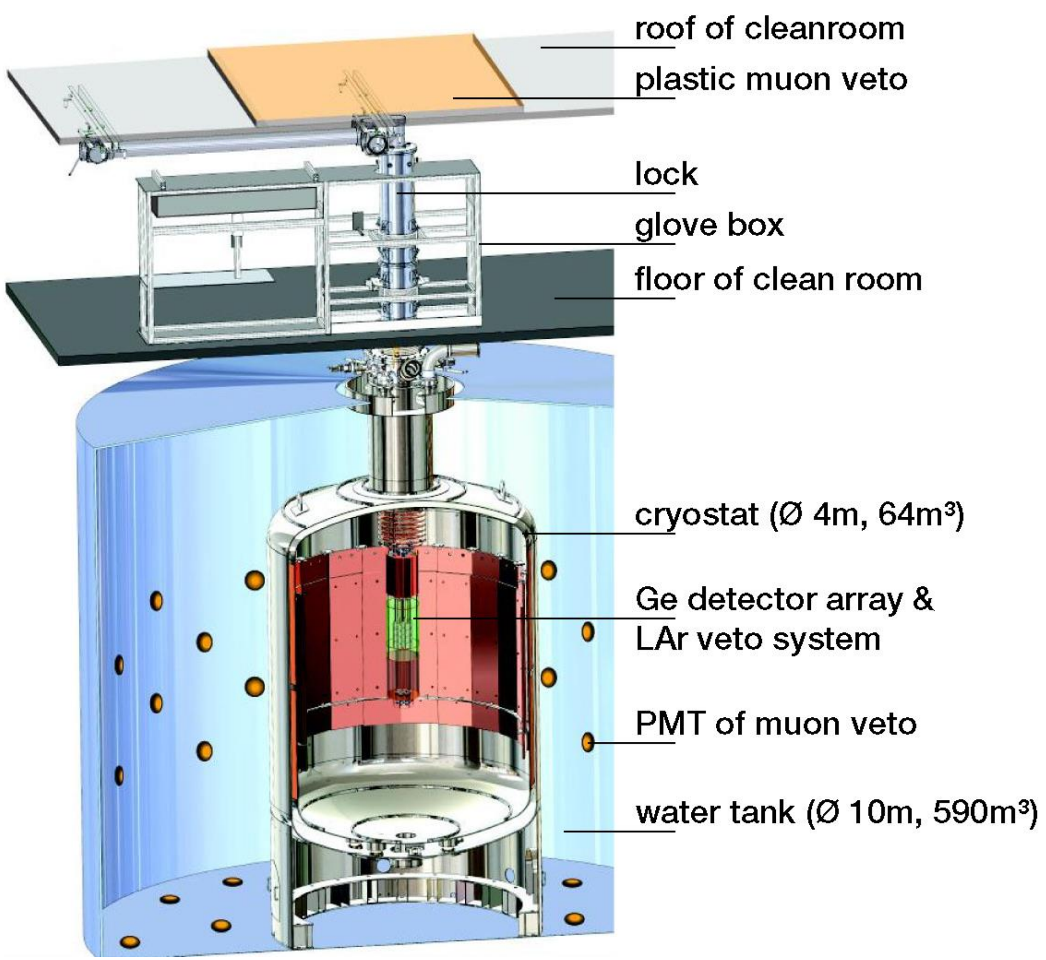
- Final results Sept 2020
  - Exposure: 103.7 kg yr
  - Limit: $T_{1/2} > 1.8 \times 10^{26}$ yr

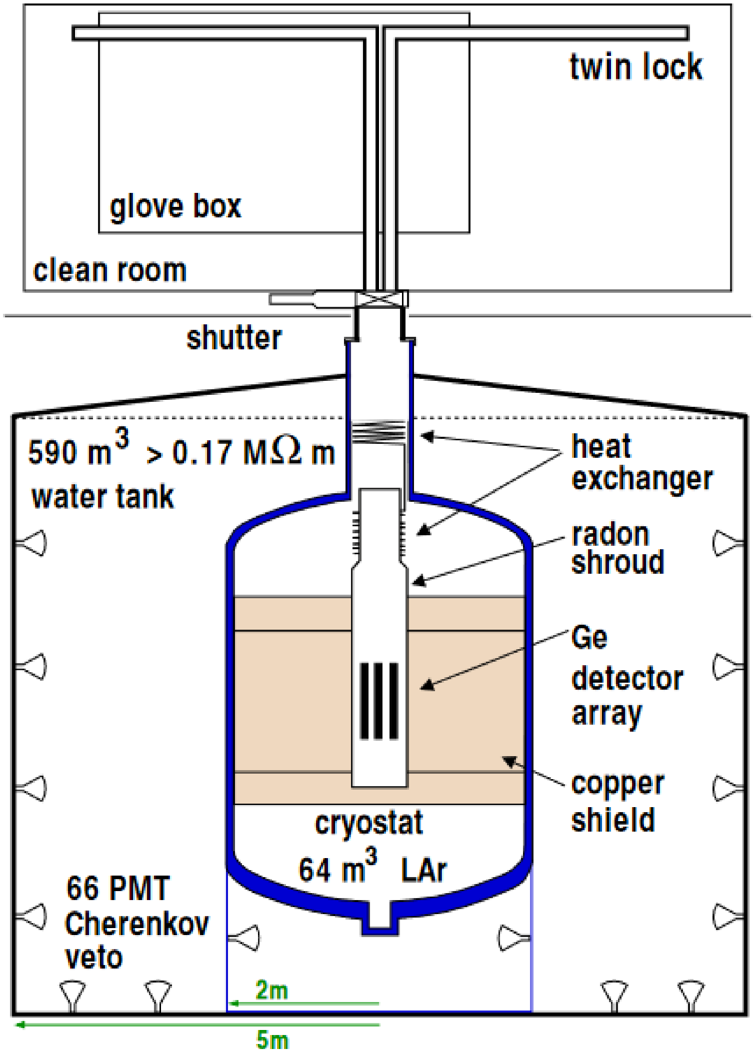
GERDA Design

- Ge detectors, 86% ^{76}Ge enrichment
- Placed in liquid argon (GERDA II)
  - Active veto
  - Cools detector to 86 K
- Surrounded by water tank
  - Muons, with scintillator panel



GERDA Design



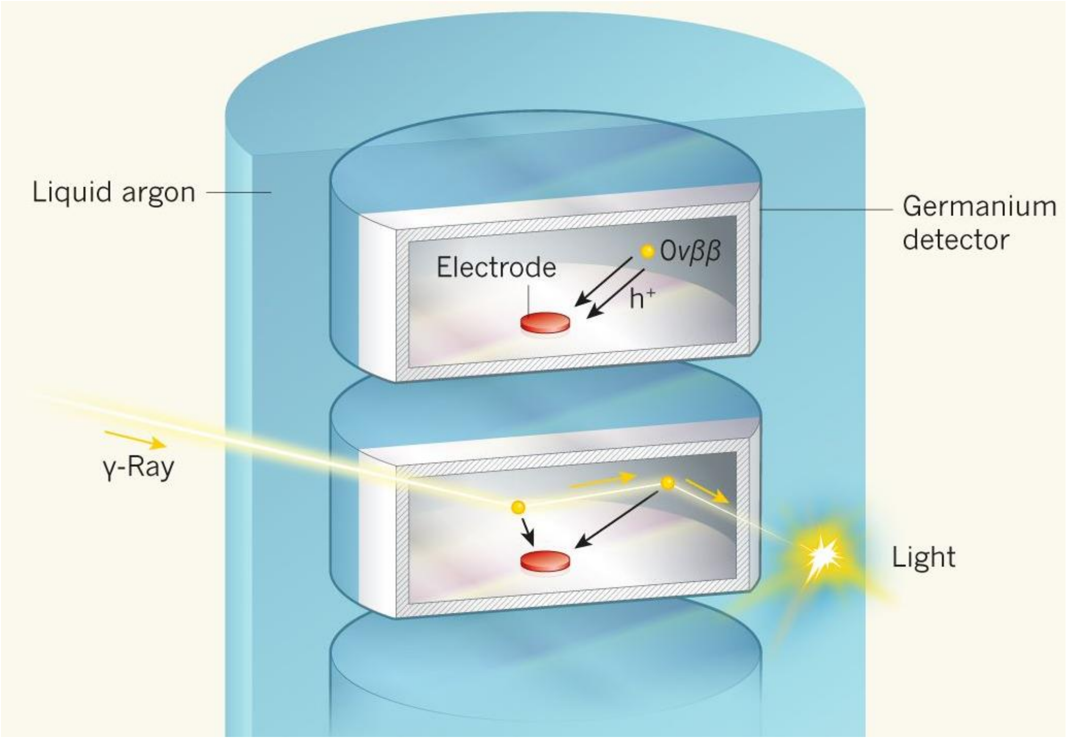


Liquid Argon Veto

- Coincidence detector with Ge
- Every photon counts!

If any of the photosensors detects a signal of at least one photoelectron within about 6µs of the germanium detector trigger, the event is classified as background. Acci-

arxiv.org/pdf/2009.06079.pdf

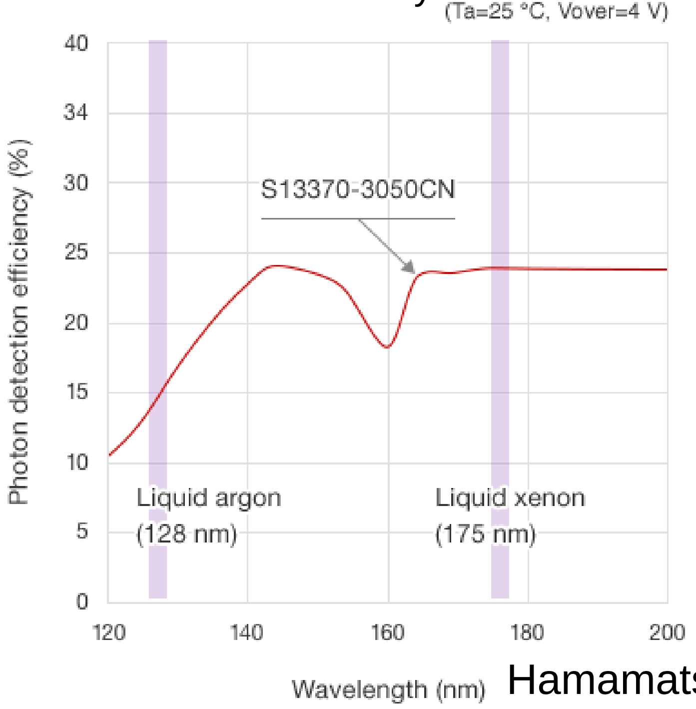


LAr Scintillation

- LAr scintillates at 128 nm (VUV)
  - LAr not transparent
  - Photodetectors less efficient

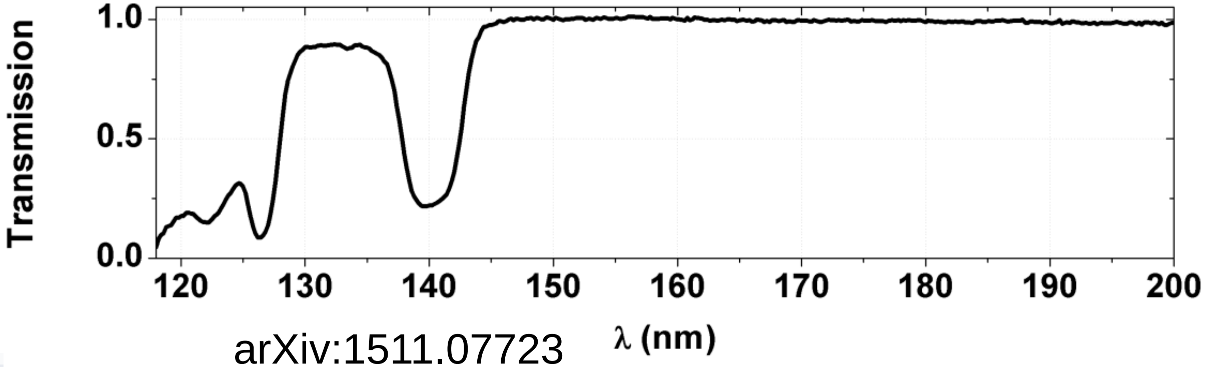
- Need to shift to higher wavelengths

SiPM Efficiency



Hamamatsu

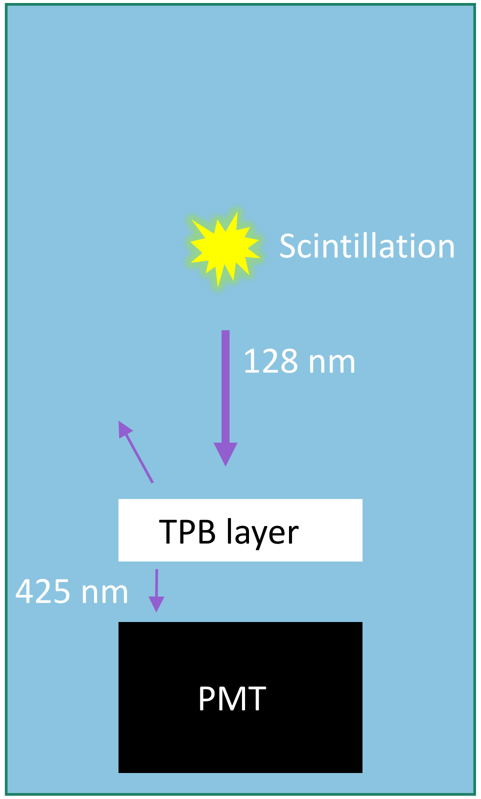
LAr Transparency



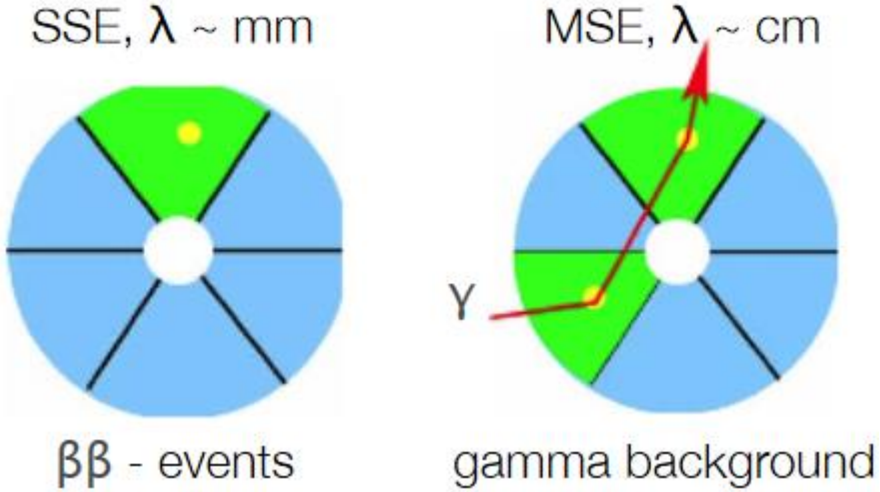
arXiv:1511.07723

TPB Wavelength Shifting

- TPB coating placed before photodetector
- 128 nm → 425 nm
- Not a perfect solution:
  - Isotropic reemission: automatic 50% loss
  - Degrades over time



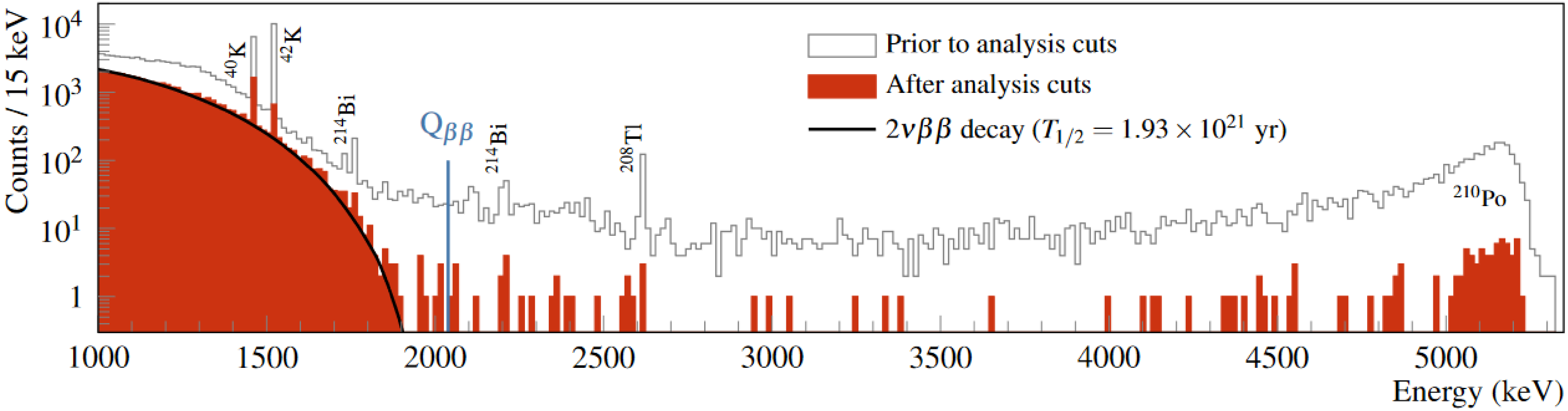
Ge PID Summary



- ββ
  - Highly localized inside Ge
- γ
  - Compton scatter, long attenuation
  - Granularity cut: signal in multiple Ge detectors → background
- α and β
  - Mostly surface events, short attenuation
  - Use pulse shape discrimination, A/E

GERDA Background

- 1.8 events/(t yr FWHM) in ROI

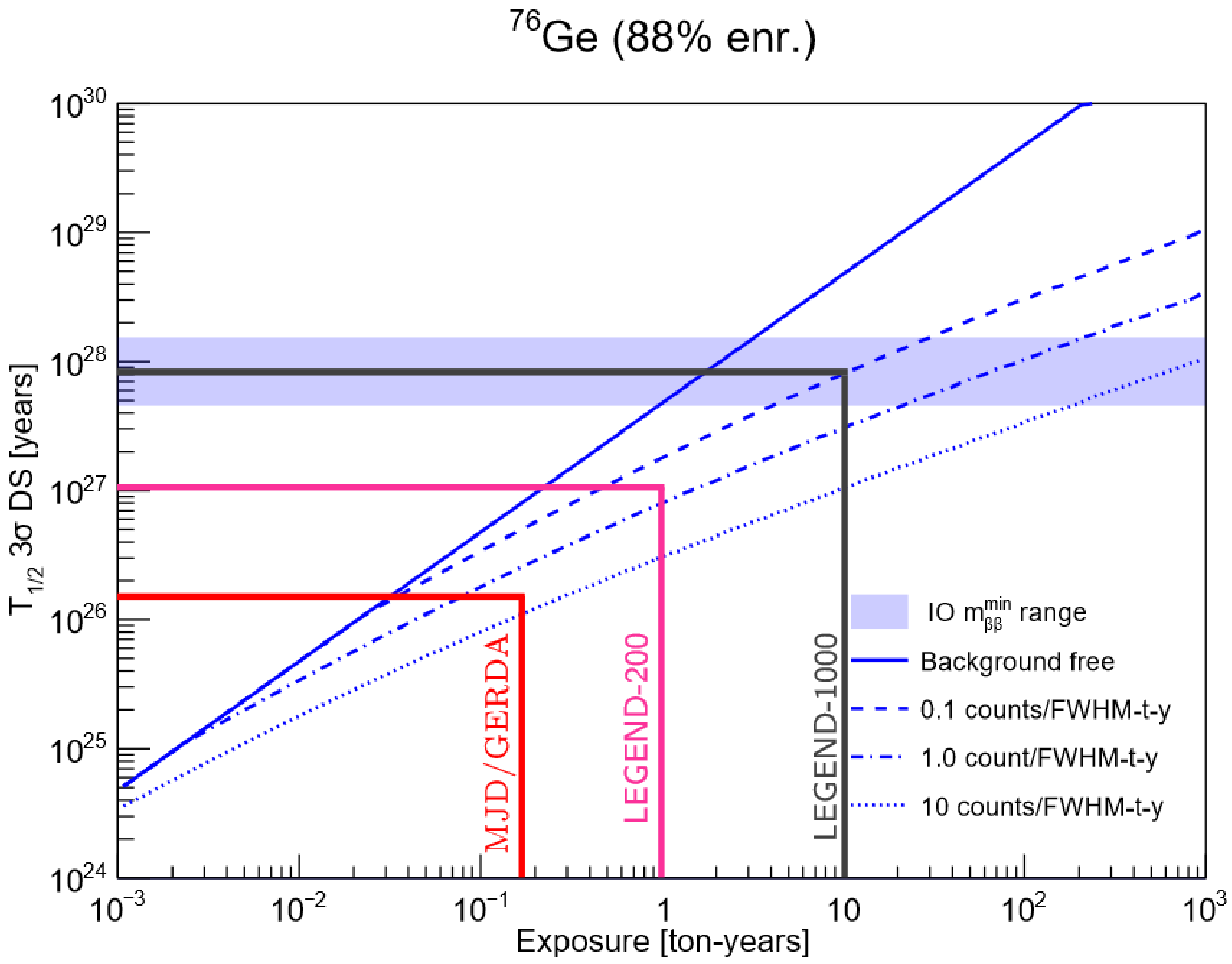


LEGEND

- **L**arge **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless ββ **D**ecay
  - GERDA + MAJORANA
  - Half-life sensitivity: > 10^{28} yr
  - Phase 1, LEGEND-200, data in 2021(?)

- Background goals in ROI:
  - LEGEND-200: < 0.6 events/(t yr FWHM)
  - LEGEND-1000: < 0.1 events/(t yr FWHM)
- Requires significant R&D

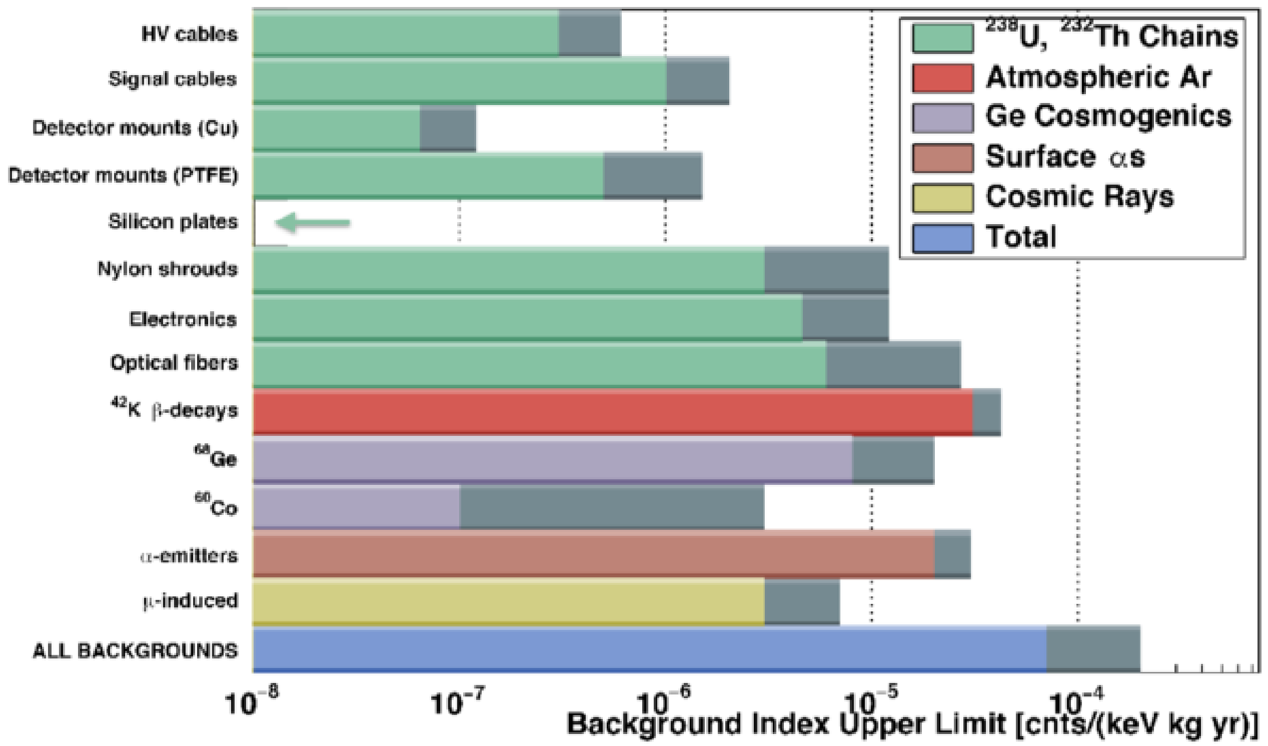
Discovery Potential!

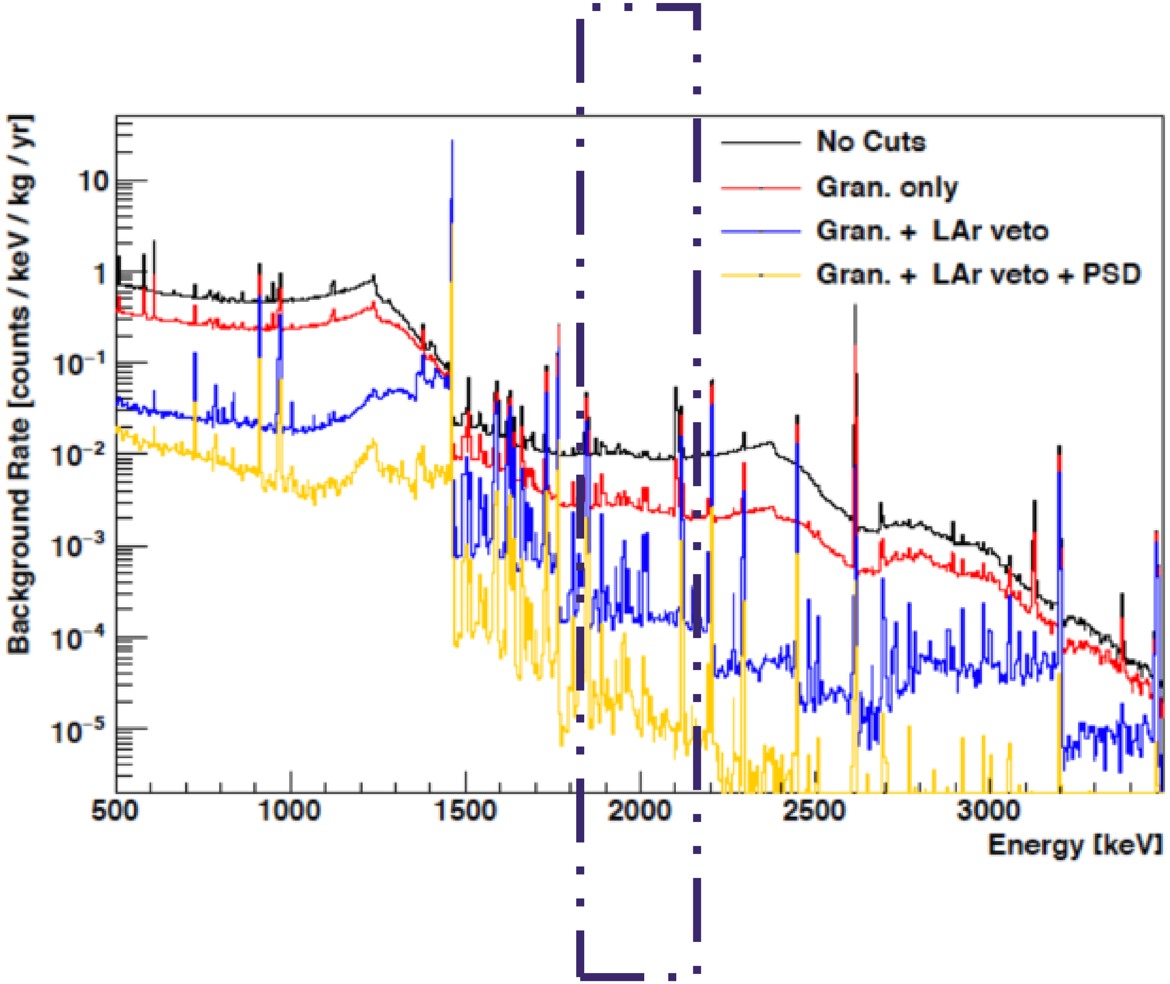


LEGEND-200 Design

- Similar to GERDA design
  - Uses existing site at LNGS.
- Scale up: 200 kg of Ge
- Improved radiopurity
  - MAJORANA electroformed copper

LEGEND-200 Expected Background





Current R&D: PEN

- Poly(ethylene naphthalate)
- Possible replacement for many inactive components
  - Self-vetoing structural material

- Scintillates at 445 nm
- Wavelengths shifts VUV → visible
- Excellent structural properties
- Easy to clean

Current R&D: LAr Xe Doping

- Transfers scintillation to Xe
- 128 nm → 175 nm

- Possible alternative/complement to TPB?
  - No LAr transmission issue
  - Avoids issues of TPB
- Recent result:
  - 10 ppm in 100 L LAr improves light yield by factor of 1.8

    https://arxiv.org/abs/2006.09780

Summary and Outlook

- $0\nu\beta\beta$ detection offers insights into new physics
  - See-saw mechanism?
  - Leptogenesis?
- Extraordinary long half-life requires near-zero background
  - Significant R&D challenges
- GERDA and MAJORANA show feasibility of large scale Ge exp
- LEGEND is upcoming 1 ton Ge experiment

References

- Older 0νββ Review Paper
- 0νββ Review Paper
- Older GERDA Presentation
- GERDA Background Paper
- Final GERDA results
- MAJORANA Presentation
- LEGEND Presentation
- LEGEND Paper 1
- LEGEND Paper 2
- PEN Presentation
- Recent LAr Xe Doping Paper