Germanium Detectors
for a one-tonne experiment

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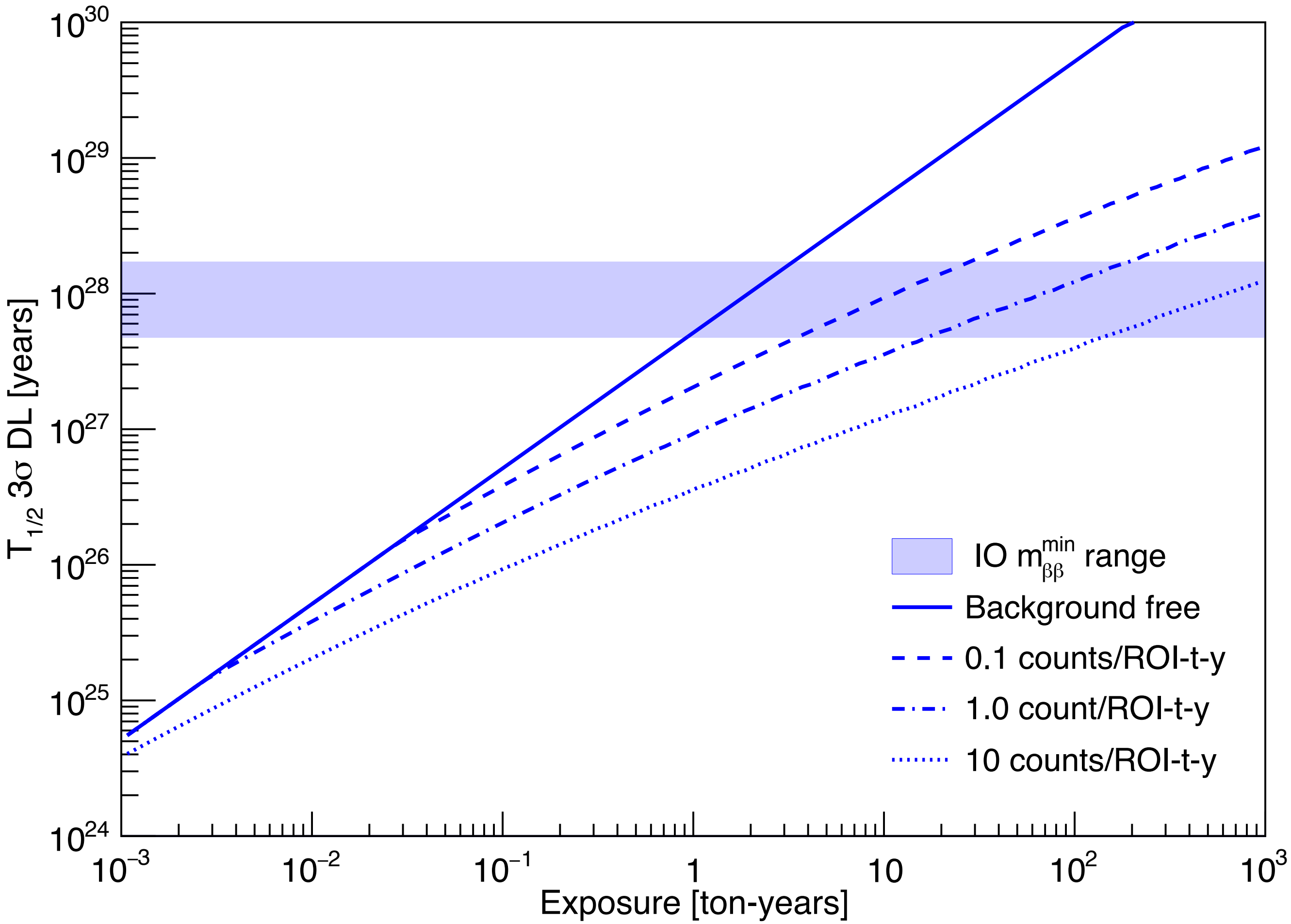
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Sensitivity for Inverted Hierarchy

To probe entire region of inverted mass hierarchy requires

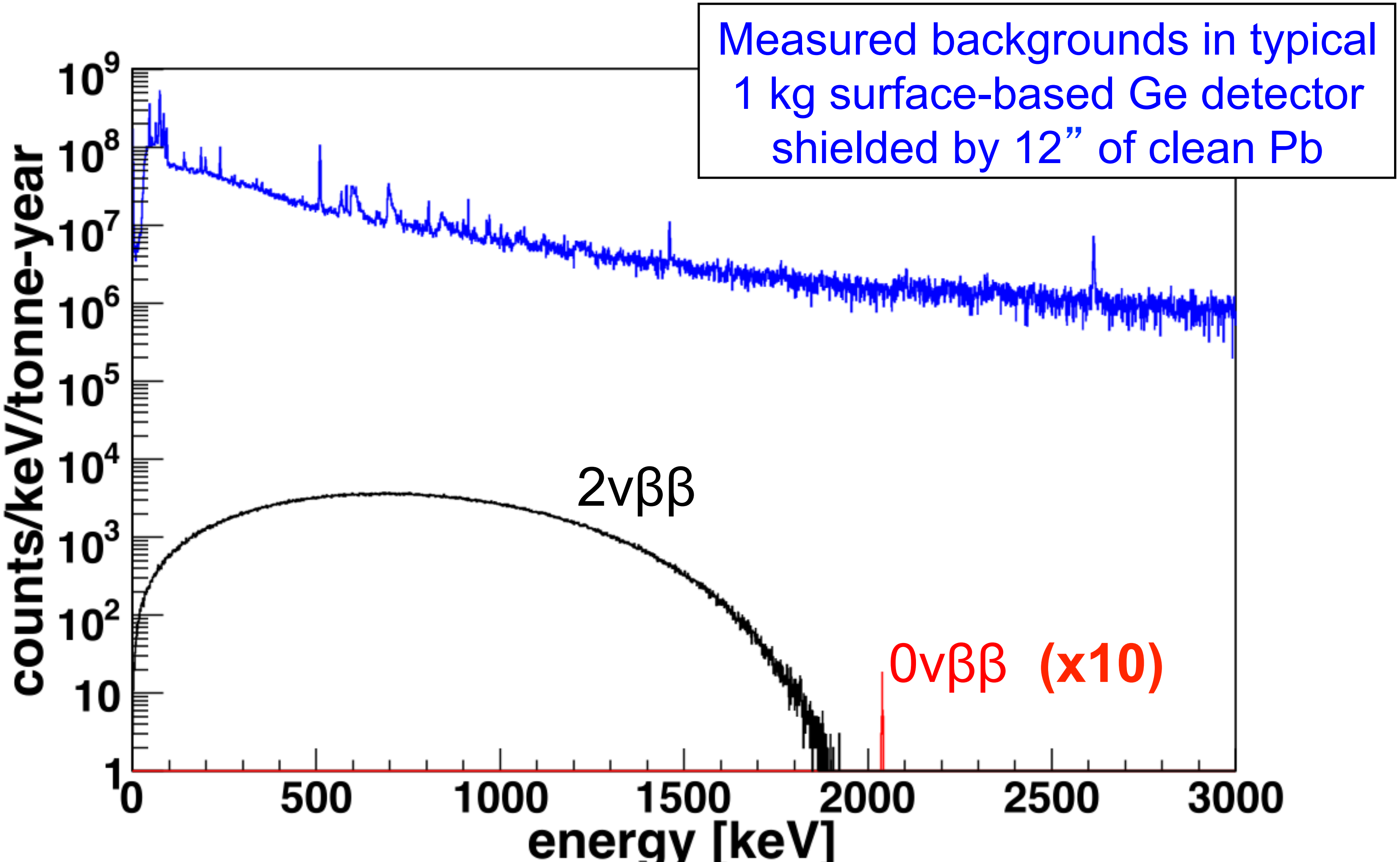
- About 10 tonne-years of exposure
- Background rates of < 1 c/t/y (ideally ≤ 0.1 c/t/y)



J. Detwiler

Sensitivity for Inverted Hierarchy

An illustration of how hard this is…



A. Schubert

What is the Ideal 0νββ Detector?

- Low Background!
  - High intrinsic radiopurity
  - Source = active detector mass
  - Shielded from surface contamination (alphas etc.)
- Excellent resolution
  - Small ROI means less background
  - No 2νββ contribution
- Modular / scalable
- Cheap and easy
  - Enrichment, production, …
- Additional physics
  - Dark matter searches, axions, …

Is ^{76}Ge the Ideal 0νββ Detector?

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- High intrinsic radiopurity
- Source = active detector mass
- Shielded from surface contamination (alphas etc.)

✓ Excellent resolution
- Small ROI means less background
- No 2νββ contribution

✓ Modular / scalable

✗ Cheap and easy
- Enrichment, production, …

✓ Additional physics
- Dark matter searches, axions, …

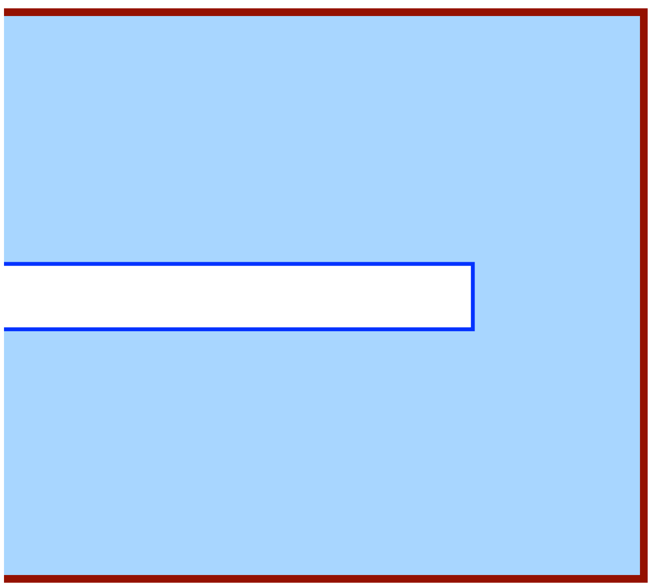
Requirements

- Simplicity
  - About one 1kg-detector per day for 3 years!
    - Easy-to-grow crystals
    - Easy-to-make detectors
    - Quick and simple to characterize
    - Easy to install
- Pulse-shape sensitivity
- Low noise and threshold
- Insensitivity to alphas
- Minimal readout electronics
- Active veto?
- Large mass?

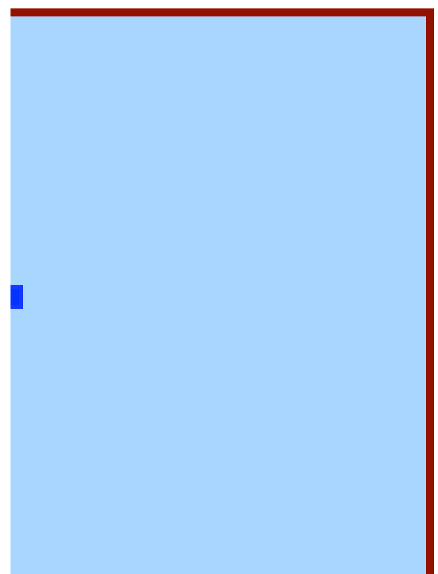
Candidate Detector Designs

- Coaxial
- Point contact
  - BEGe
  - “PPC”
  - Larger versions?

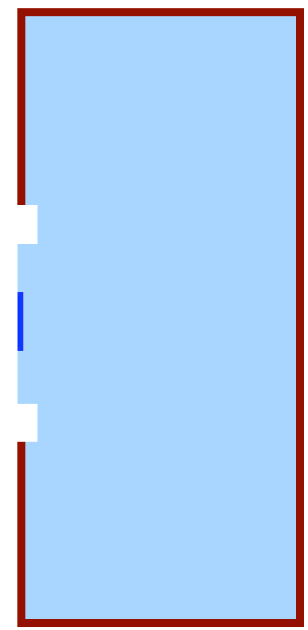
- All are well understood, reasonably simple to produce and characterize,



Closed-end coaxial



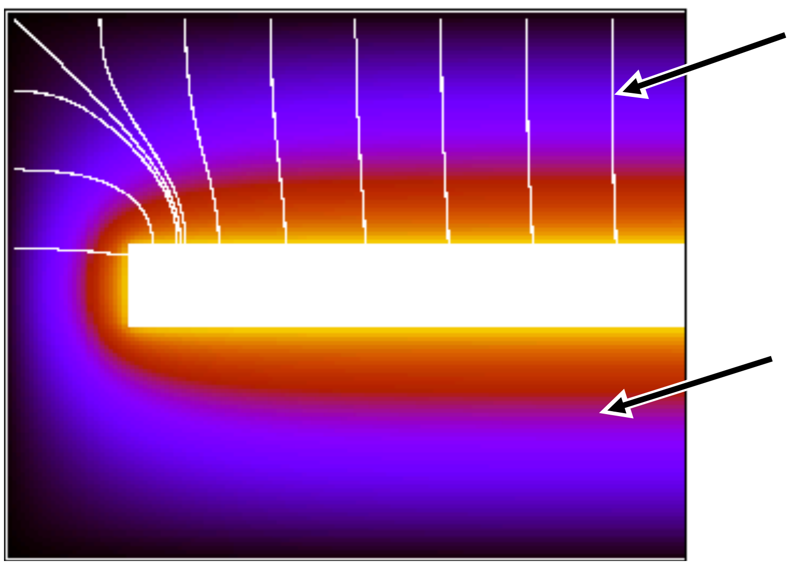
“Standard” PPC



BEGe

Coaxial

- Long-time standard technology
- Poorer PSA background rejection (GERDA)
- Poorer threshold and resolution at low energies; no DM search
- Large central contact (and passivation?) is susceptible to alphas
- Masses up to 1.5 kg easily, maybe 3 kg with some effort (9x9 cm)



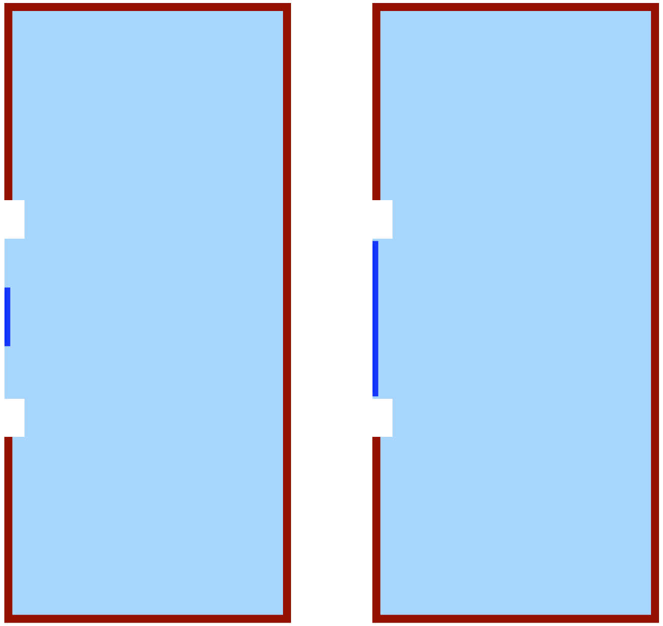
Drift paths of electrons and holes

Weighting potential

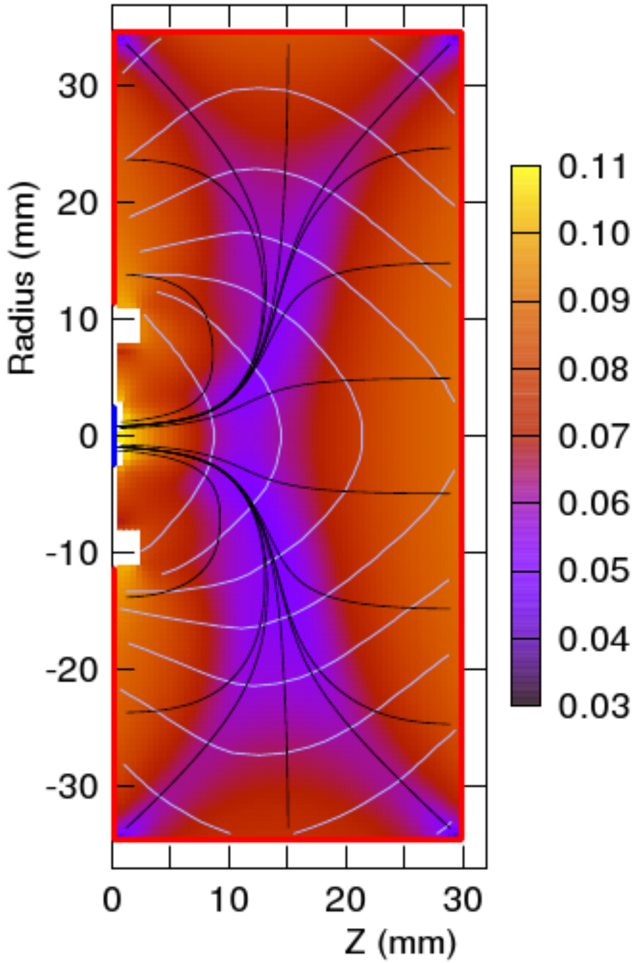
- Used to calculate induced signal as a function of the charge position
- Relatively diffuse

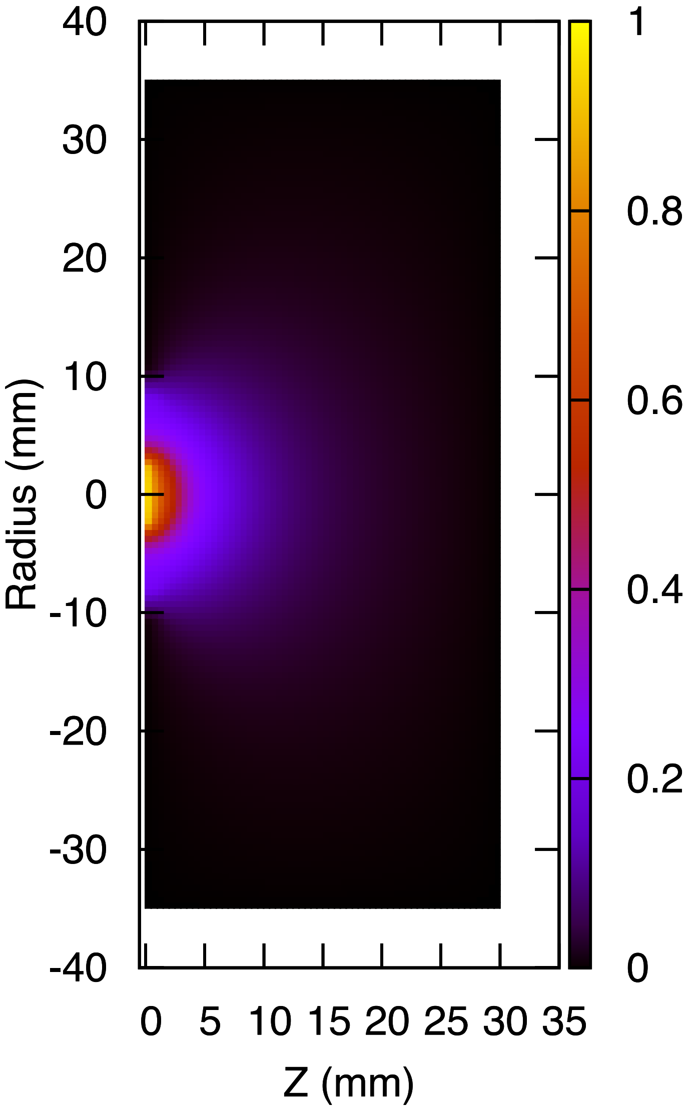
BEGe

- Also standard technology, for over a decade
- Generally good PSA background rejection
- Low capacitance; good threshold and resolution at low energies
  - Have been used for DM searches
- Wrap-around Li
  - Protects for alphas
- Masses limited to ~ 1.0 kg (9x3 cm)
- Two slightly different styles
  - Meriden (USA)
  - Olen (Europe)



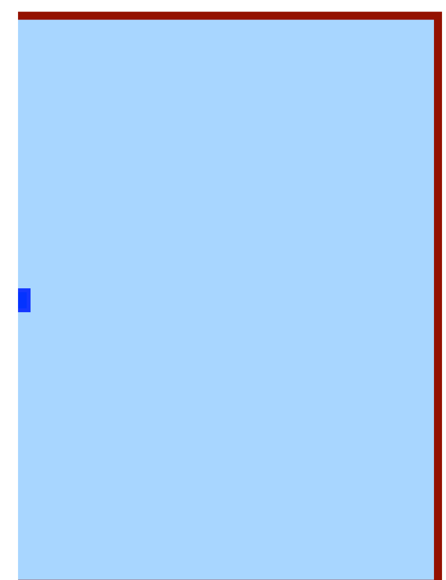
Drift and WP for a BEGe (Meriden design)



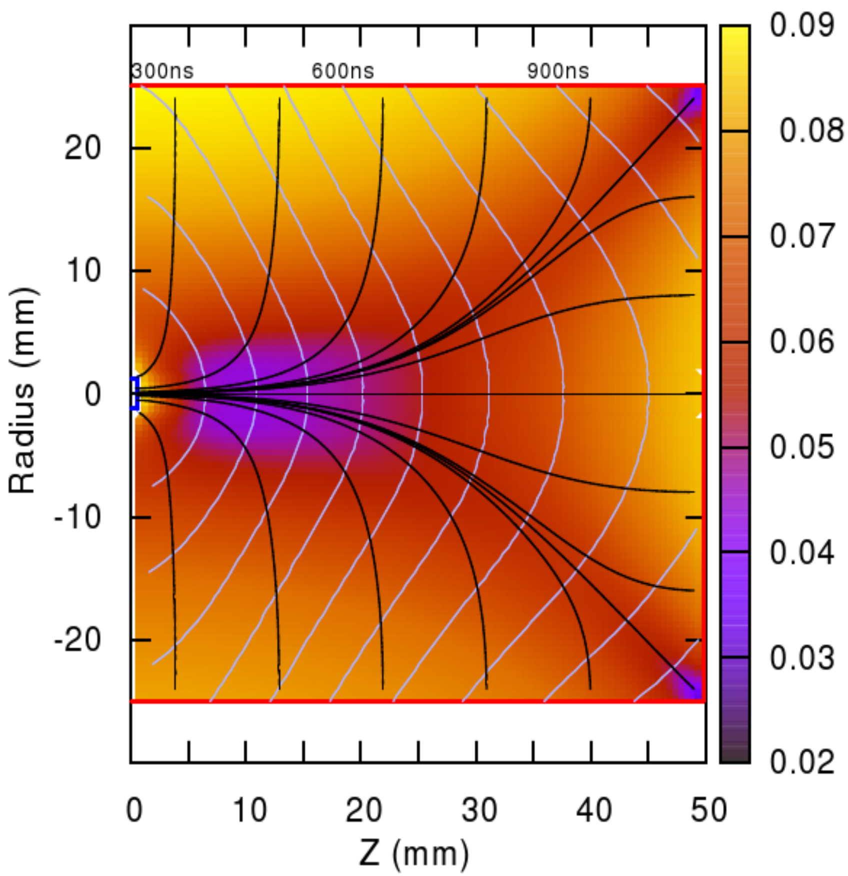


ORTEC-style PPC

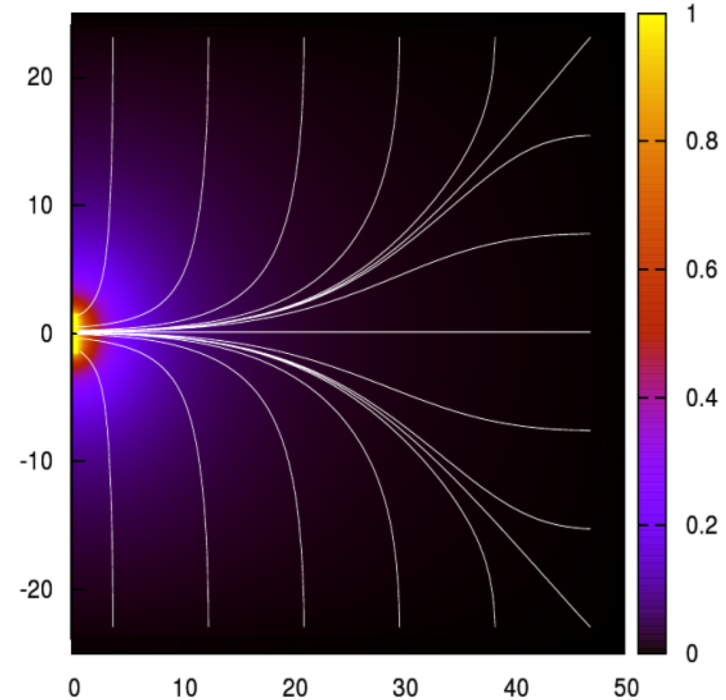
- Relatively new technology
- Currently available only from ORTEC?
- Good PSA background rejection
- Low capacitance; good threshold and resolution at low energies
  - Have been used for DM searches
- Low leakage currents (not tested in LAr)
- No wrap-around Li
  - But PSA for alphas appears to work well
  - Needs further testing
- Masses limited to ~ 1.3 kg ? (8x5 cm)



Drift and WP for a generic PPC



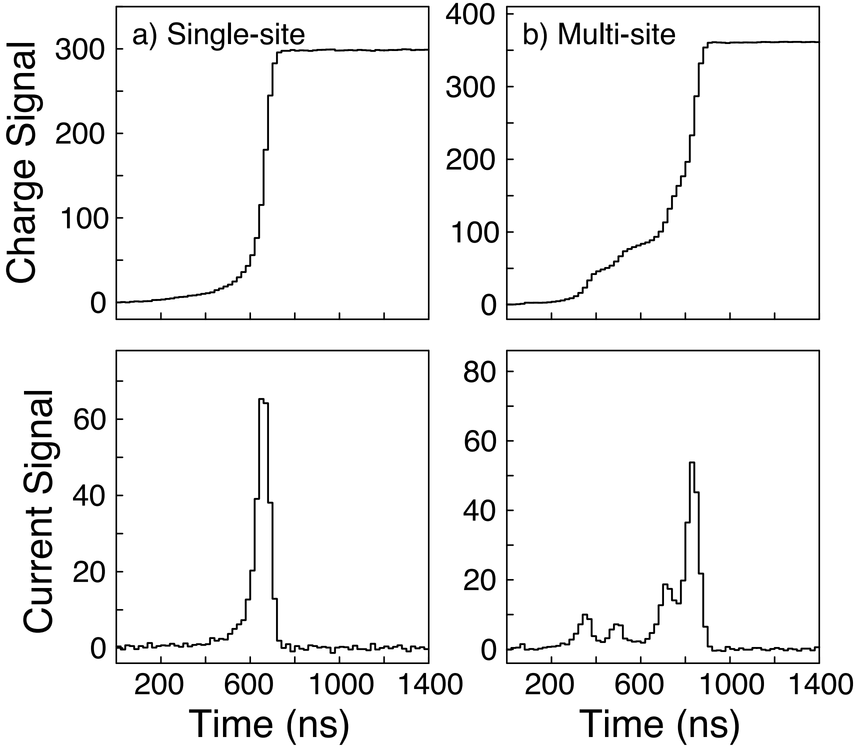
Drift velocity, paths, times



Weighting potential

Signal Shapes and Pulse-Shape Analysis

- $0\nu\beta\beta$ events are inherently single-site
- But gamma rays usually interact multiple times in detectors
  - Several Compton scatters, followed by photoelectric effect
- BEGe / PPC detectors give unique sensitivity to multiple interactions
  - Long charge drift times
  - Localized weighting potential
  - Separate current pulse for each charge cloud
- Allows for excellent rejection of multi-site gamma backgrounds, and of alphas



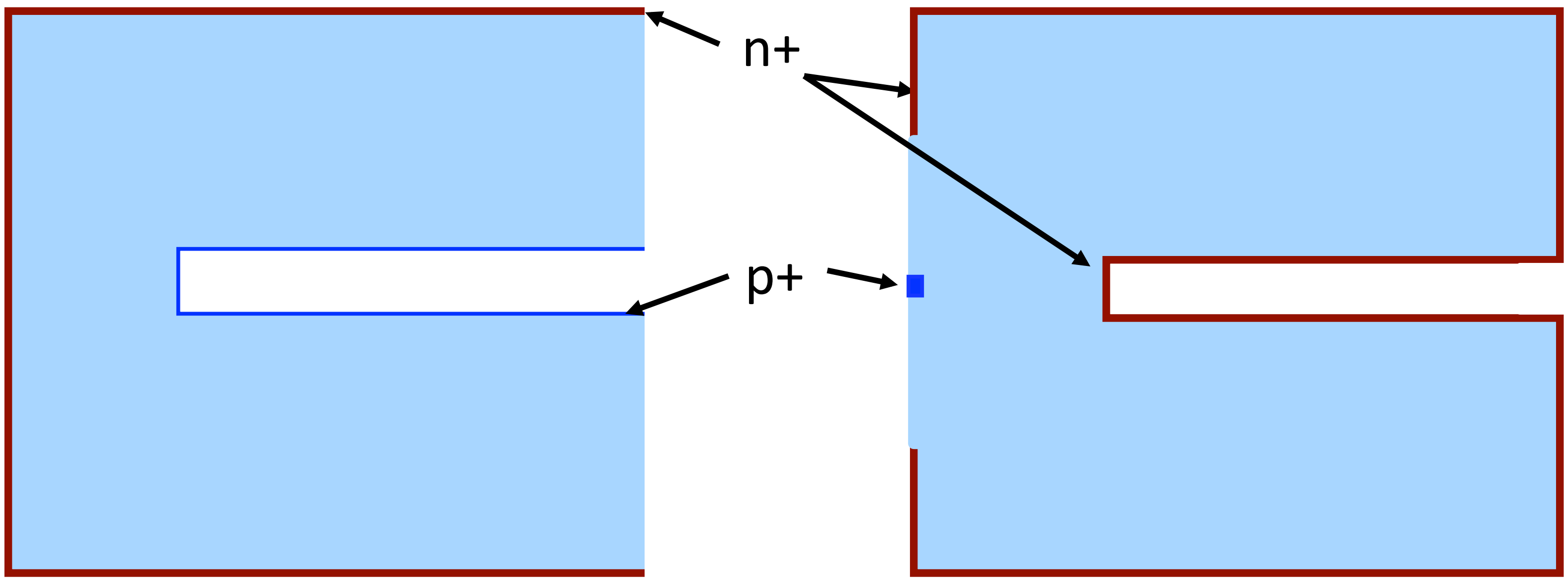
Large Point Contact Detectors

- Point contacts have lower backgrounds and lower thresholds
- But normal point-contact detectors are limited in size
  - Long crystals result in “pinch-off”, an undepleted region in the middle of the detector

- If we could increase their size, we would
  - Improve ratio of active mass to dead mass / bkgnd
  - Improve volume-to-surface ratio
  - Reduce testing and handling underground

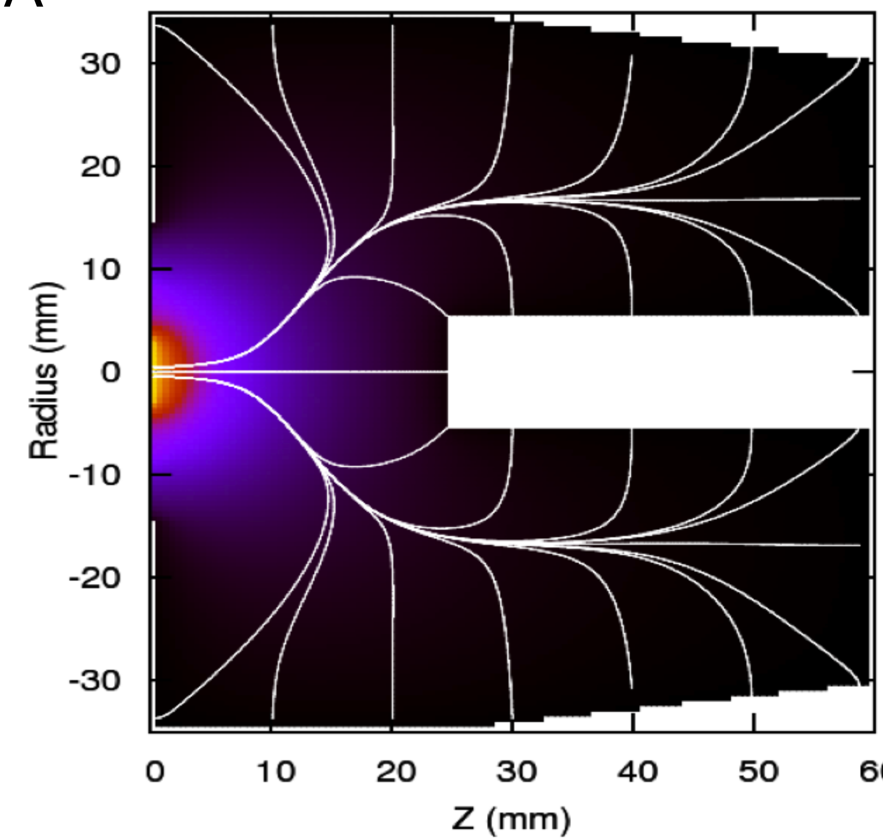
Large Point Contact Detectors

- Point contacts have lower backgrounds and lower thresholds
- But normal point-contact detectors are limited in size
  - Long crystals result in “pinch-off”, an undepleted region in the middle of the detector
- To overcome this, developed new “Inverted Coaxial” design



Inverted-coaxial PPC detectors?

- CANBERRA Meriden made a p-type prototype for ORNL
  - 7 x 6 cm, 1.0 kg
  - Wrap-around Li, similar to a BEGe
  - 1.8 keV @ ^{60}Co, excellent PSA
- They now sell a version of this detector as a SAGe Well Detector
- Tapering the crystal improves depletion and charge drift
- Could try using no taper on outside, but tapered inner hole
- Simulation codes already developed and validated on 1.0 – 1.5 kg prototypes



New ORNL LDRD Proposal

- In process

CANBERRA

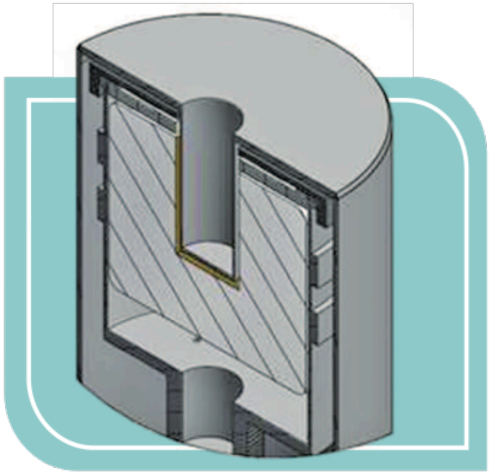
Small Anode Germanium (SAGe) Well Detector

Features & Benefits

- Blind well approaches 4π counting geometry yielding high absolute efficiency
- Superior resolution compared to Traditional Well Detectors at both low and high energies
- Larger well diameter (28 mm) available with the same excellent resolution as the standard (16 mm) well sizes
- Thin lithium diffused contact inside well allows spectroscopy from 20 keV up to 10 MeV
- Full LabSOCS™ characterization available, allowing True Coincidence Summing correction

Description

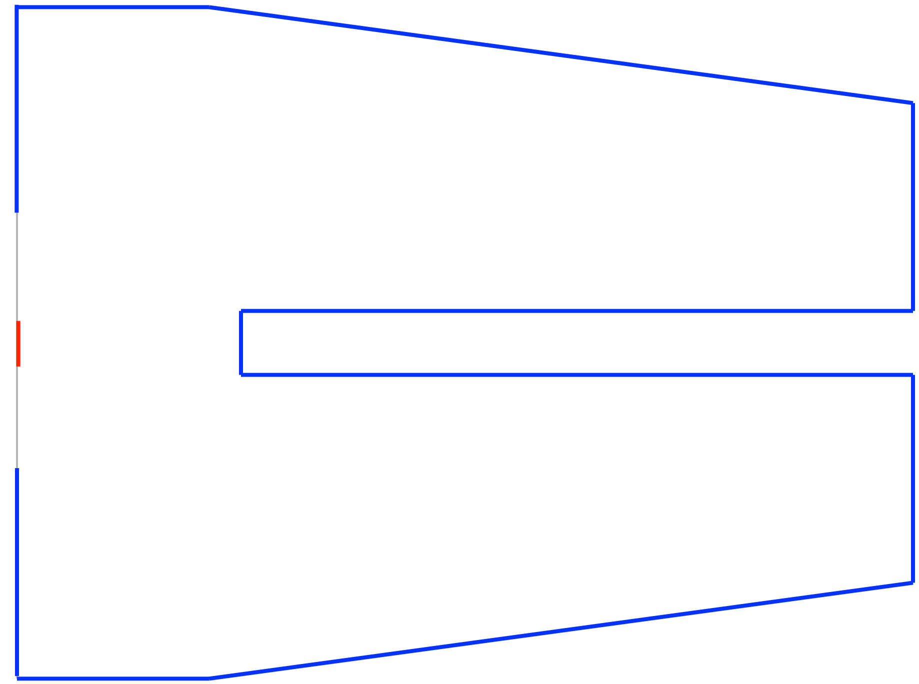
The CANBERRA SAGe™ Well Detector[1] combines excellent energy resolution at low and high energies with maximum efficiency for small samples. Like Traditional Well Detectors, the SAGe Well is fabricated with a blind hole, leaving at least 20 mm of active detector thickness at the bottom of the well. The counting geometry therefore approaches 4π.



The low detector capacitance associated with the small anode technology (similar to what is used on CANBERRA's BEGe detectors) gives the SAGe Well superior low and medium-energy resolution performance compared to Traditional Well or Coaxial Detectors, as well as excellent resolution for higher energy gamma rays.

Larger Mass?

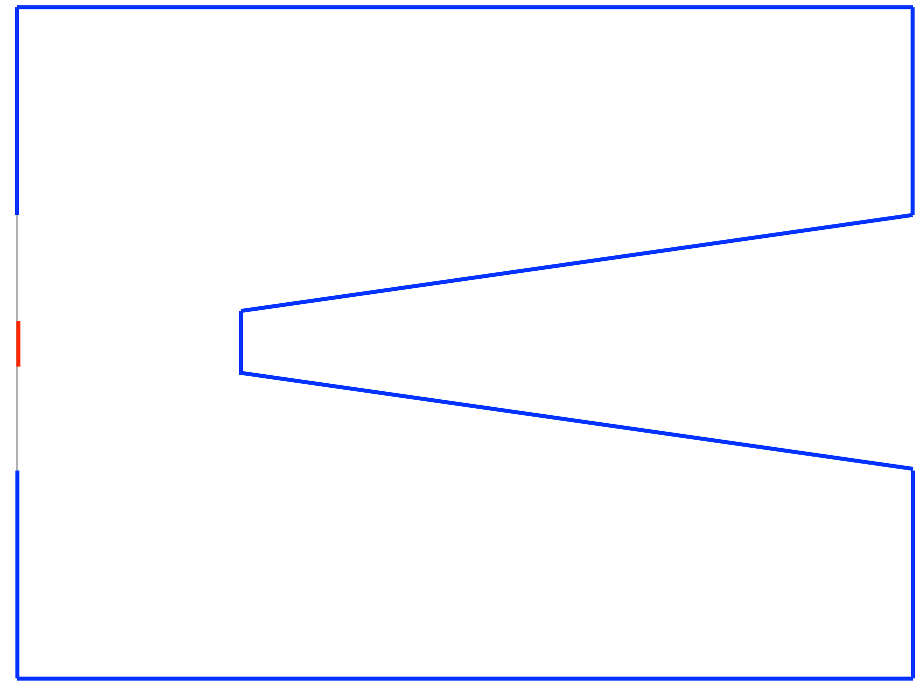
- Increase both radius and length of detector
  - Need to properly evaluate trade-offs regarding yield vs. size
  - Need to test charge trapping and CT correction
- Taper cylindrical outside
- 9 – 10 cm diameter
- Up to 10 cm length
- Mass ~ 2.7 – 3.4 kg



- First simulations:
  - ρ ~ 1.5e10 , D = 9 cm depletes at < 4 kV
  - D = 10 cm gets hard to deplete
  - Rather poor field inside

Larger Mass?

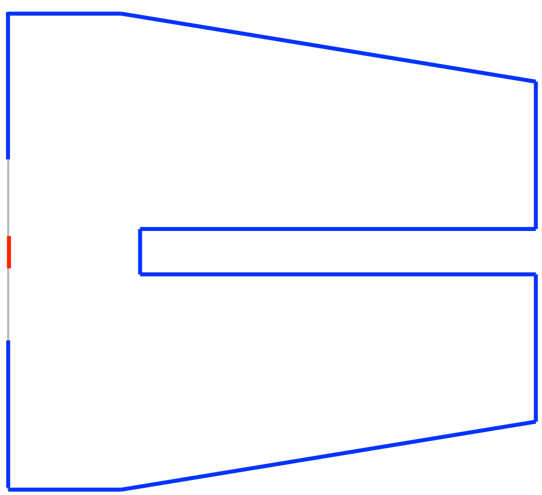
- Taper cylindrical hole
- 9 – 10 cm diameter
- Up to 10 cm length
- Mass ~ 3.1 – 3.9 kg

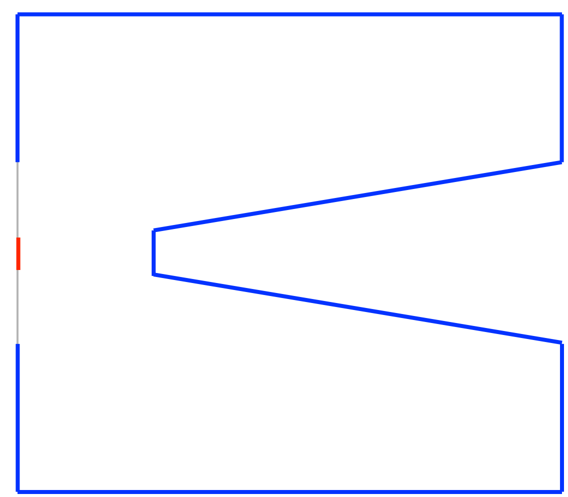


- First simulations:
  - ρ ~ 1.5e10 , D = 9 cm depletes well at < 4 kV
  - D = 10 cm depletes OK?
  - Better field inside, easier / more flexible control
  - Less removed mass (~ 300g)

ORNL LDRD Proposal

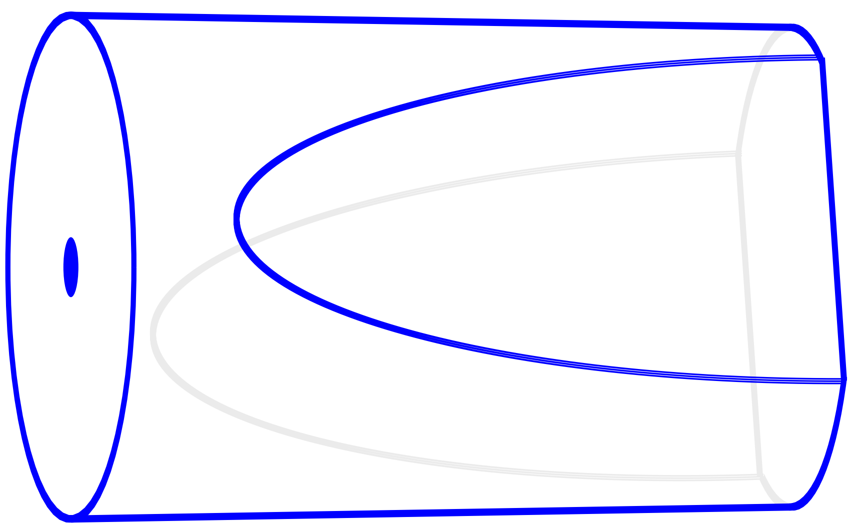
- Application in process
- Develop new larger detector designs
  - Up to 3 kg (9 x 9 cm)
  - Work with detector makers, buy one or two ^{nat}Ge prototypes
  - Could be reused as assay system

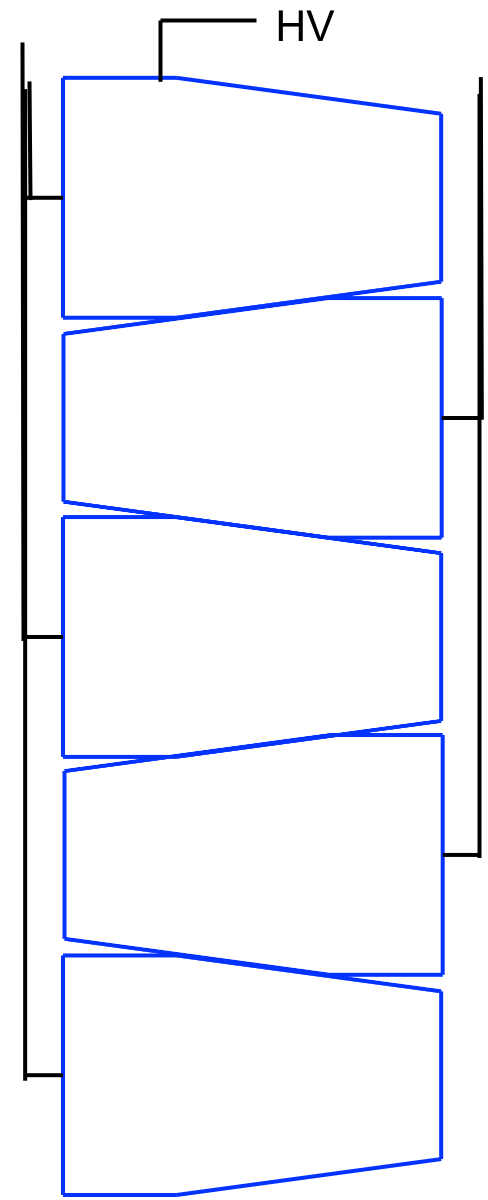




Another Idea: Stacked Detectors

- Cylindrical PPC detector with two angled planar cuts on the outside
  - Need simulations to verify good depletion
  - Will require efficient recycling of enriched material
- Choose detectors with common op. voltage
- Stack them with the flat sides touching and bias them with a single HV channel





Readout Technology

- Need better, cleaner cabling systems
- Completely reliable, ultra-low mass, ultra-clean connectors
- CMOS?
- ASICS?
- Ge FETs?
- Pulsed-reset FETs with optical reset?

Lower Temperature?

- Some active veto options may require lower operating temperatures
- Recent work by Paul Barton at LBNL
  - CMOS rather than JFET
  - Excellent noise resolution
- May have serious resolution problems from charge trapping

Summary

- Some version of p-type point contact detectors is the right choice for a tonne-scale ^{76}Ge 0νββ search
- "Inverted Coax" design shown to work very well at 7 x 6 cm
  - 1.8 keV @ ^{60}Co, excellent PSA
- We should start now to try to make 2 – 3 kg versions
  - Test charge drift and charge trapping
  - Test operation in LAr and/or other active veto
  - If promising, explore production yield
- Investigate novel stacking arrangements
- Find and remove origin(s) of alpha contamination