P-Type HPGe Ring Diode Detectors for use in 0νββ Decay Experiments

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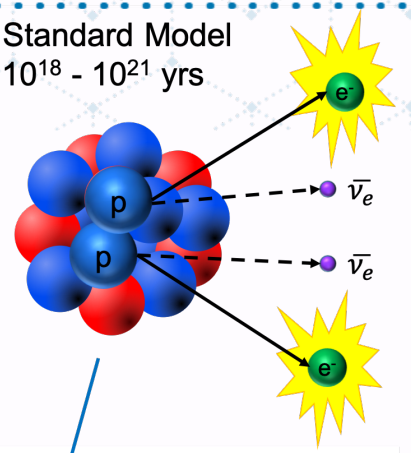
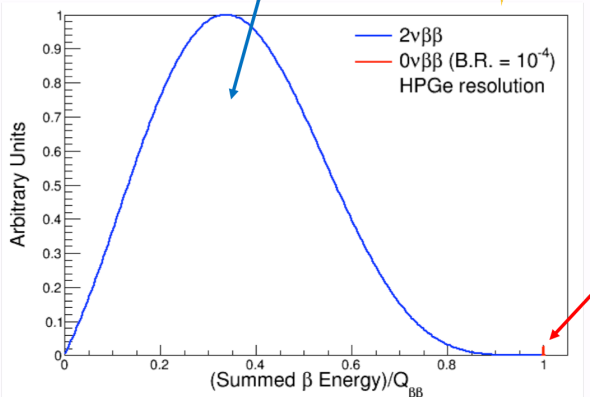
2νββ and 0νββ

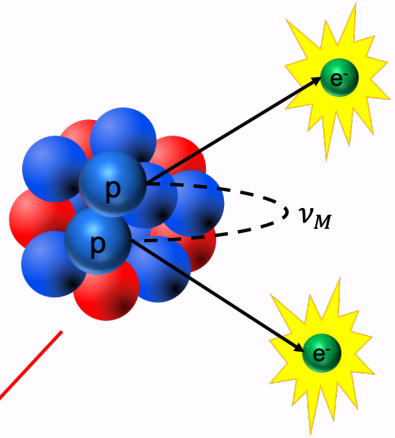
2νββ – Standard Model
$\tau_{1/2} = 10^{18} - 10^{21}$ yrs



2νββ has been observed

Decay rate is inversely proportional to half-life





0νββ is proposed

0νββ – New Physics!
$\tau_{1/2} > 10^{26}$ yrs

Simulated 2νββ and 0νββ spectra in Ge76
Source: MAJORANA

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Implications of 0νββ if Discovered

- Physics beyond the Standard Model
  - Lepton number violation
  - Information about absolute neutrino mass scale
  - Neutrino is a Majorana fermion
  - Would provide mechanism for observed matter/antimatter asymmetry

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.”

Source: LEGEND

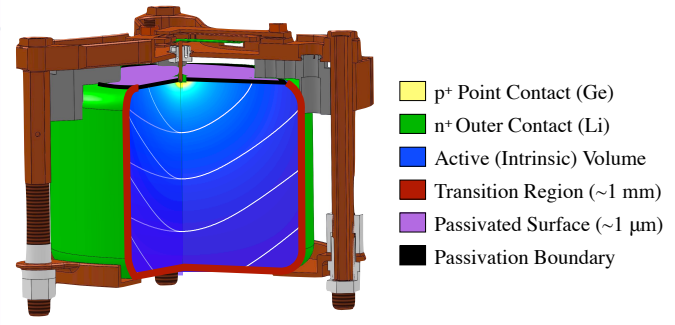
Germanium

- Semiconductor
  - High Purity Germanium Detectors (HPGe)
    - Good energy resolution for gamma ray spectroscopy
    - Operates at ~80 K
- ^{76}Ge decays into ^{76}Se via 2νββ
  - Possibly also via 0νββ
    - Half-life > 10^{25} - 10^{26} years

Ionizing radiation produces electron-hole pairs

Source: Mirion Technologies, Inc.

Single-Site v. Multi-Site Event Discrimination



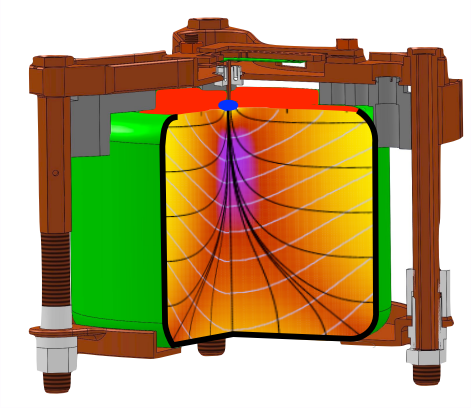
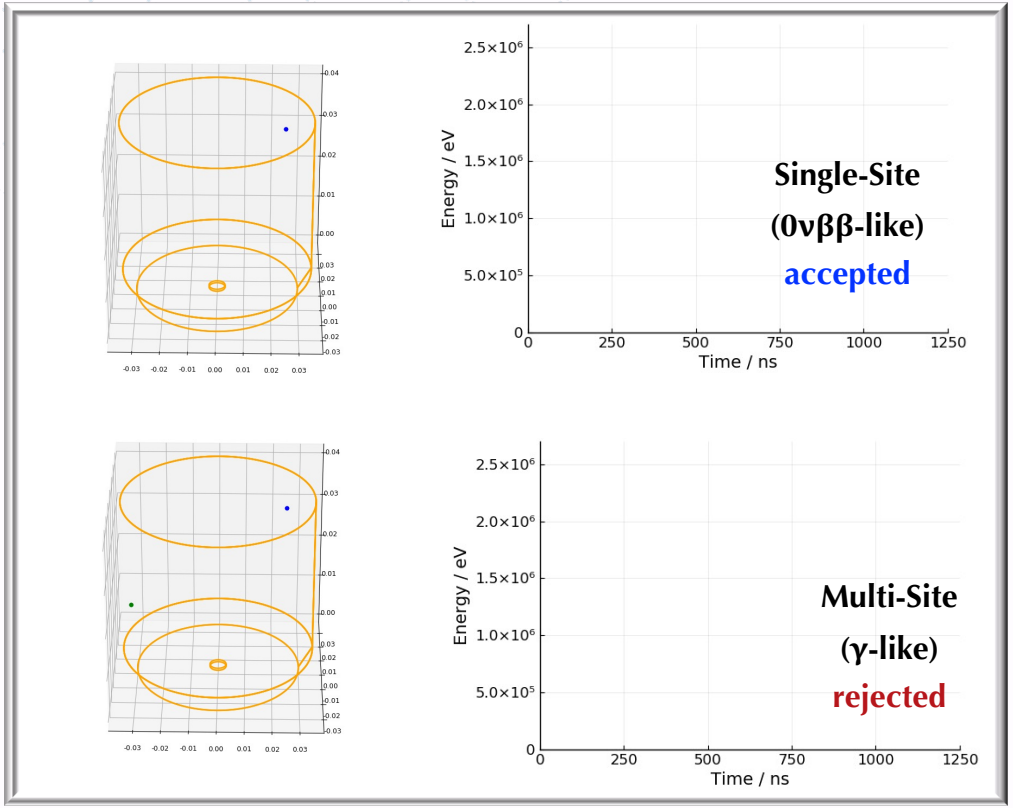


Fig. courtesy of C. Wiseman



Courtesy of David Hervas

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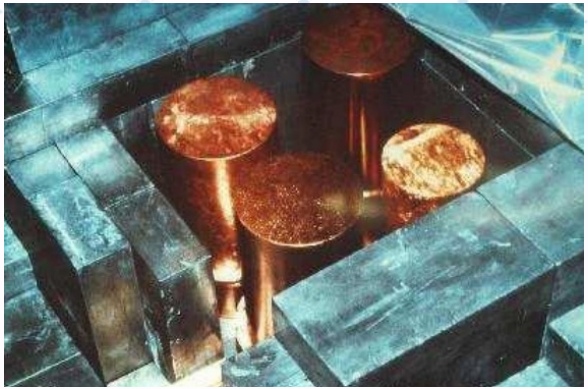
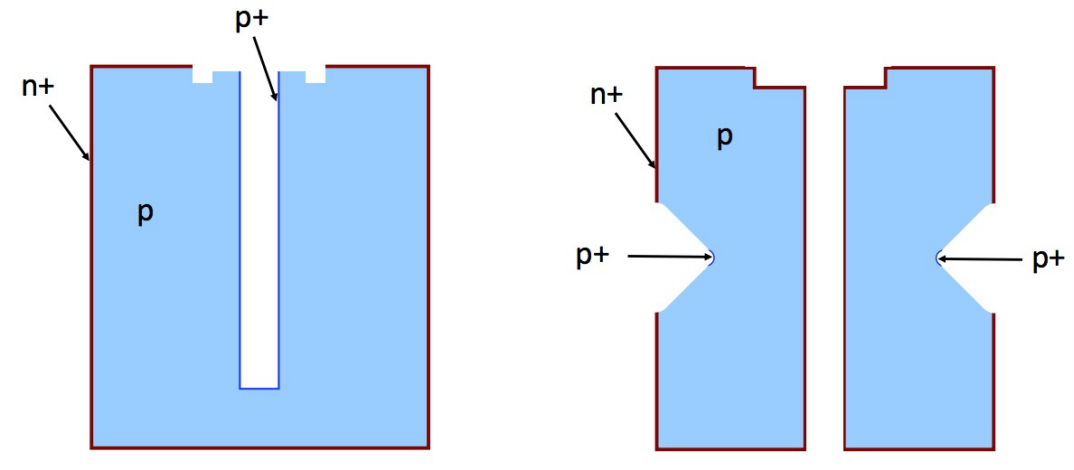
Detector Geometries



Semi-coaxial detectors from Heidelberg-Moscow experiment.

Source: H. V. Klapdor-Kleingrothaus ***et al.***, Eur. Phys. J. A., 12 (2001)



Cross section of semi-coaxial design (left) and the new proposed ring-diode detector (right).
Source: Reine, *et al*.

Simulating the Fields

Poisson's Equation

- Solved in The Julia Programming Language
- Used Solid State Detectors Package

$$\nabla^2 \phi = \frac{\rho}{\varepsilon}$$

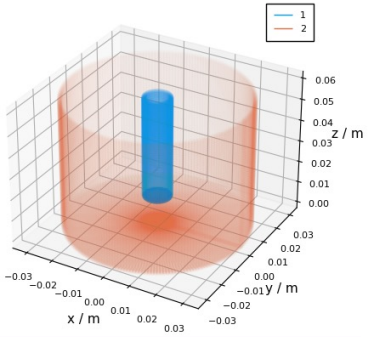
ϕ = electric potential

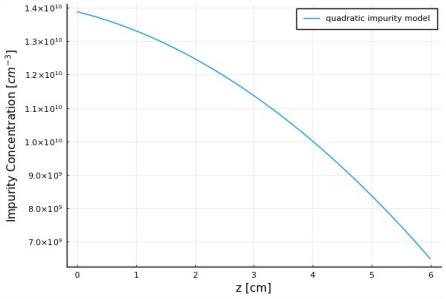
ρ = charge density

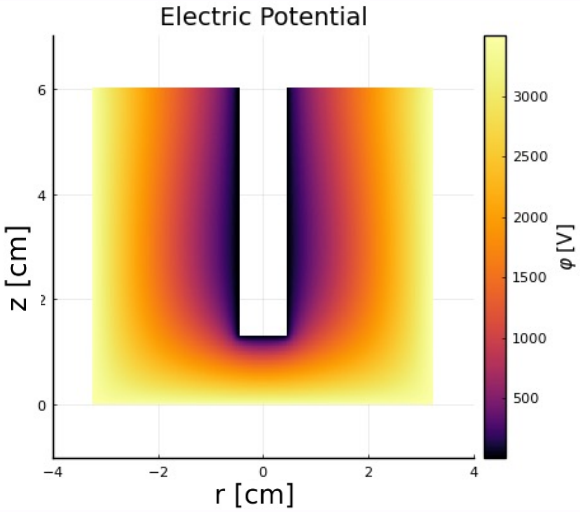
ε = dielectric constant

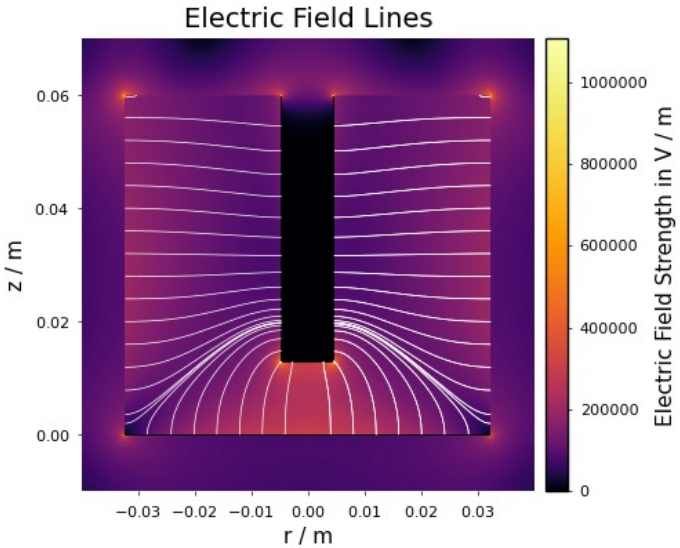
Simulations

Bias Voltage: 3500V
Simulated Depletion Voltage: 2700V



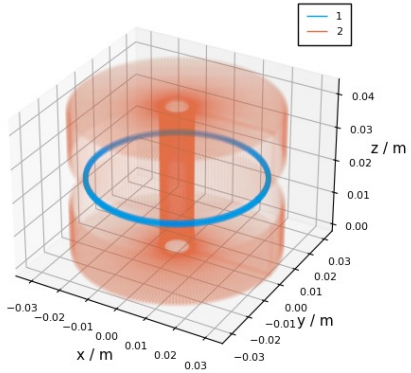


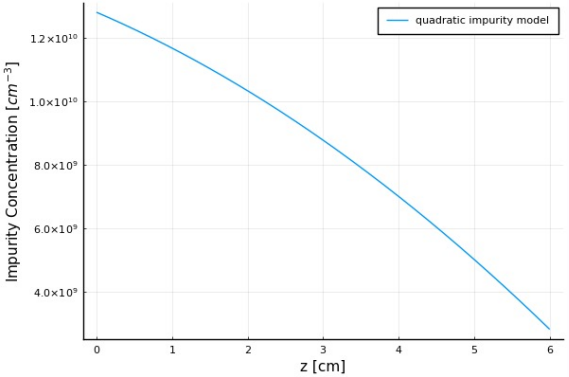


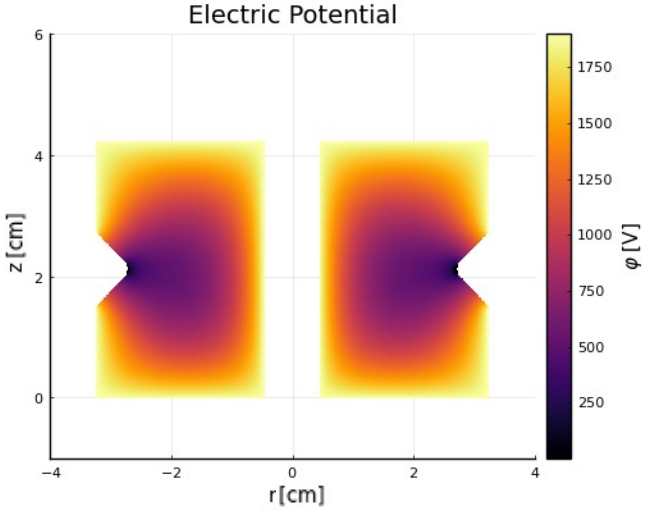


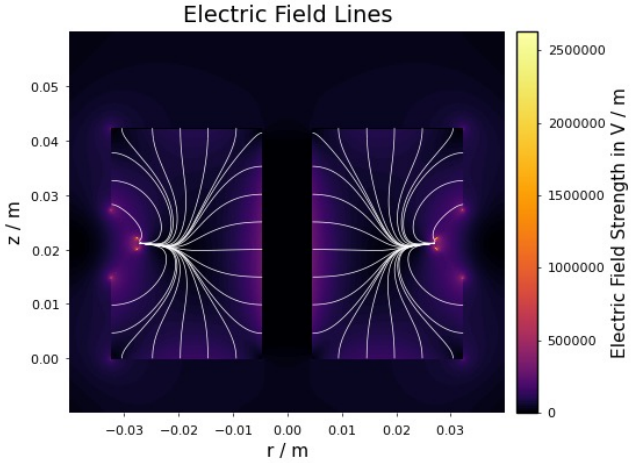
Simulations

Bias Voltage: 1900V
Simulated Depletion Voltage: 1450V



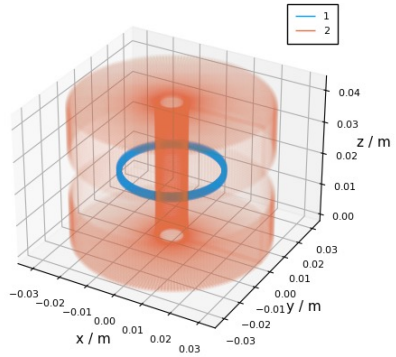


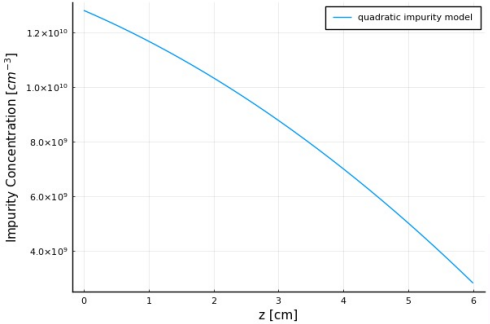


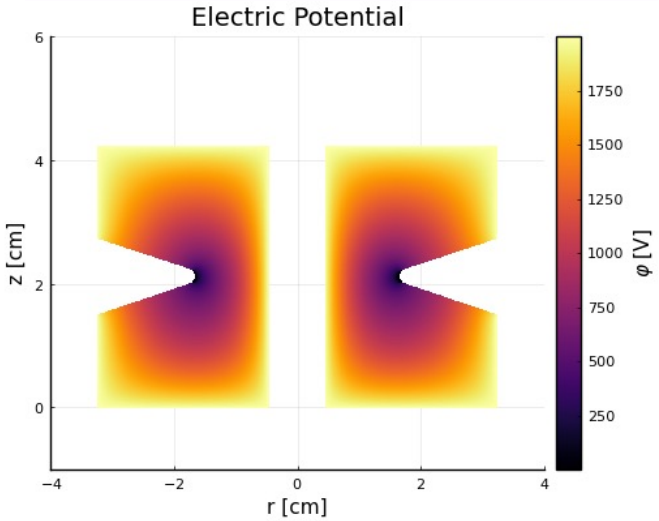


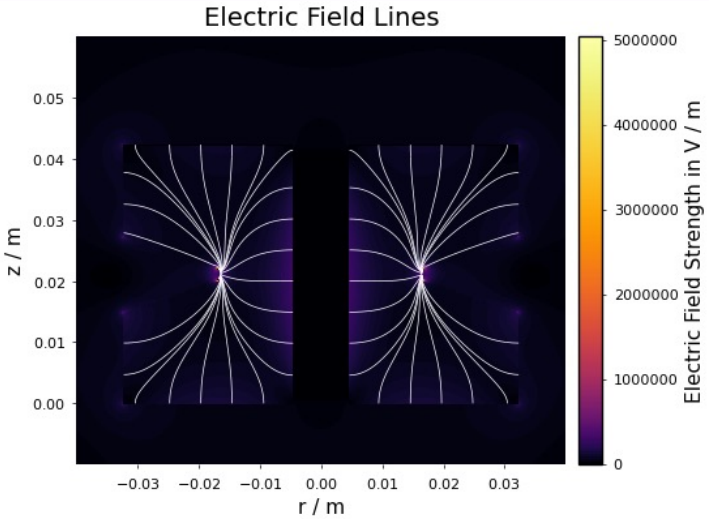
Simulations

Bias Voltage: 2000V
Simulated Depletion Voltage: 1100V





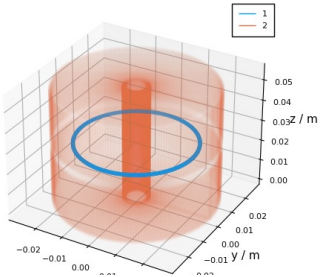


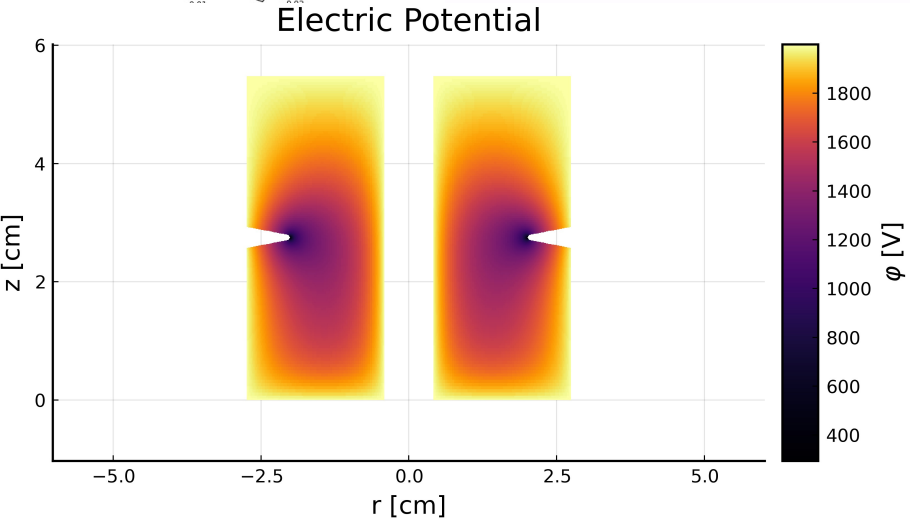


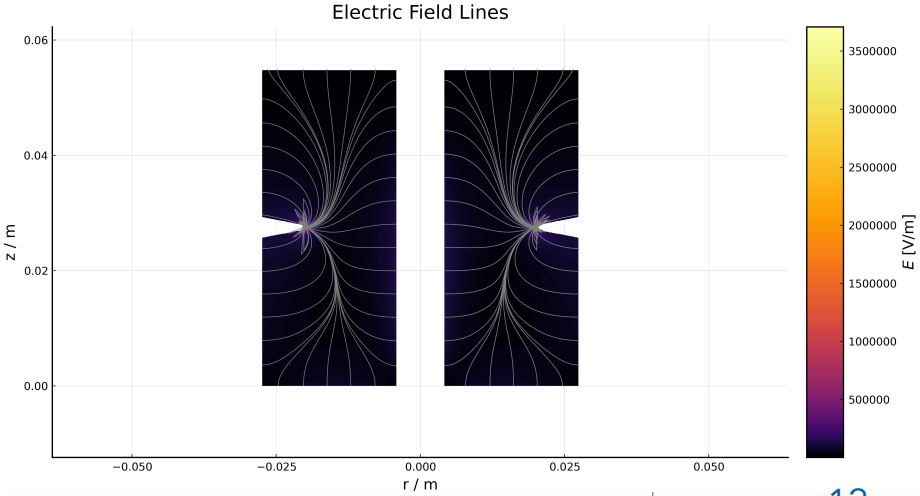
Simulations

Bias Voltage: 2000V
Simulated Depletion Voltage: 700V
Linear Impurity Profile

- Impurity at Z=0: -8E9 cm^{-3}
- Gradient: 1.55E9 cm^{-4}



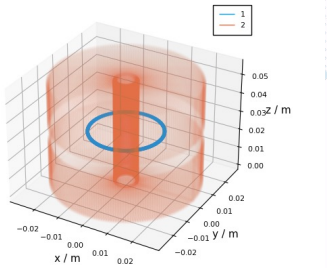


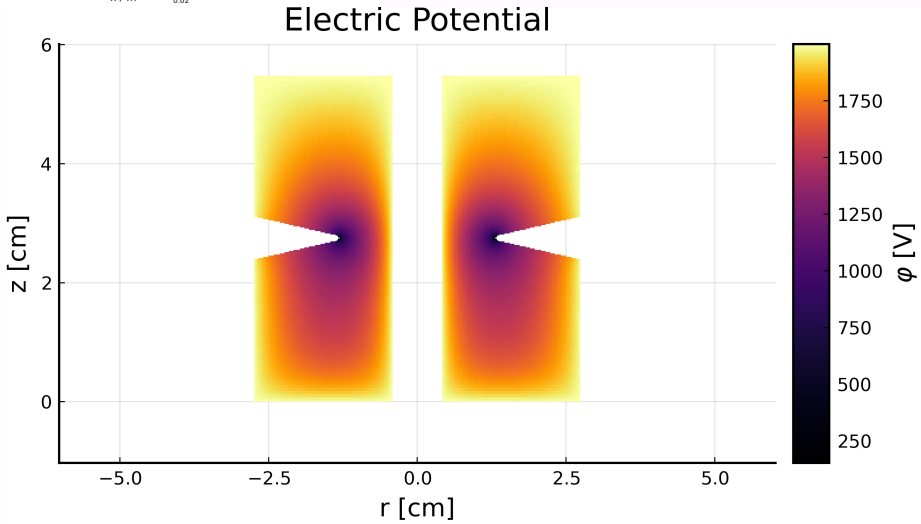


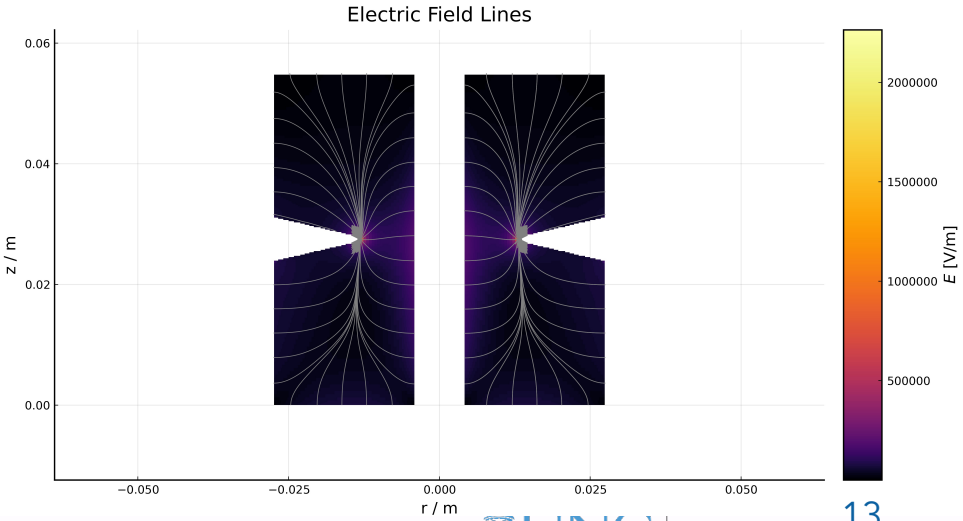
Simulations

Bias Voltage: 2000V
Simulated Depletion Voltage: 500V
Linear Impurity Profile

- Impurity at Z=0: -8E9 cm^{-3}
- Gradient: 1.55E9 cm^{-4}







Discussion and Conclusion

- Feasible to manufacture
  - *Reine et al.*
  - Suggested Pulse Shape Discrimination Abilities
- Texas A&M Manufacturing
  - Future experimental analysis and comparison with simulations
- Future work to simulate pulses of single-site and multi-site events

Acknowledgements

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Sources

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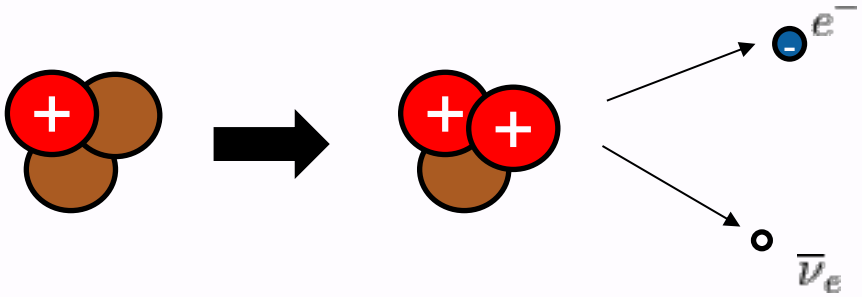
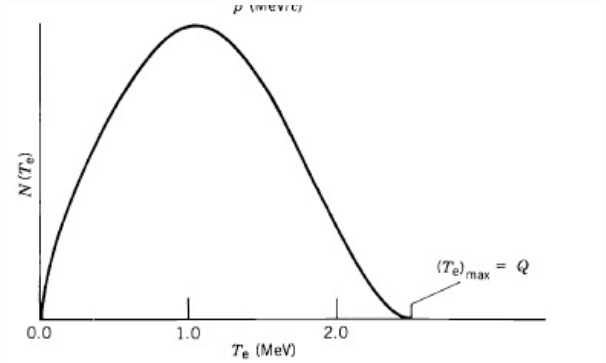
β-Decay

$$(A, Z) \rightarrow (A, Z+1) + e^{-} + \overline{\nu}_e$$

- Ex: β-Decay of Tritium

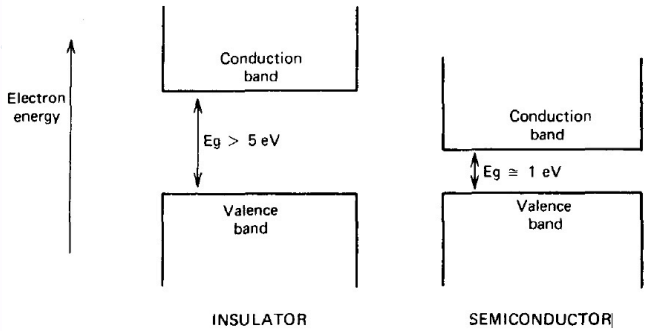


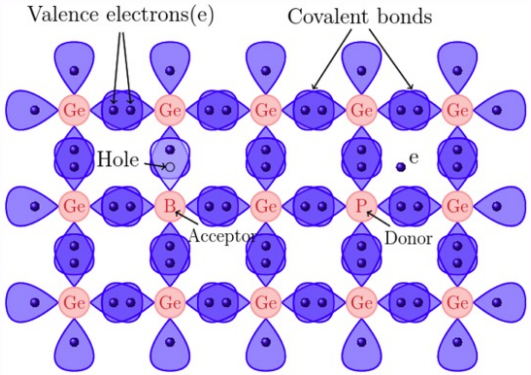


Source: Krane

Germanium Detectors

- Apply potential difference across detector
- Create “depletion region”
- “Extra” electron-hole pairs travel across potential difference





Sources: Knoll, MAJORANA