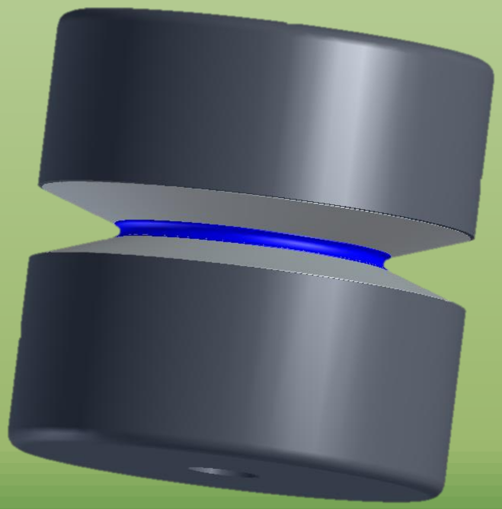
LARGE VOLUME RING-CONTACT HPGE DETECTORS (RCD)

NP SBIR Phase II Year 1

20220823 NP SBIR Exchange Meeting Zoom

Ethan Hull (PI)
CEO and Technical Director, PHDS Co.



PHDS Co. History

- Est. Fall 2004 – Nuclear and Solid-State Physics Origin – DOE Labs (LLNL, LBNL)
  - History: Custom Nuclear-Physics Detectors (Lab)
  - Recently: Modular HPGe Systems (Lab and Field)
- Complete Germanium Manufacturing + R&D at PHDS Co.
  - Concept Design
  - Crystal Growth [2012]
  - Detector Fabrication
  - System Integration
  - Software application
  - Sales & Service

Enabling Capabilities

PHDS Gamma Ray Detectors

Science Experiment

NPX (150 lbs.)
2008 Laboratory

Versatile Global Commercial Product

GeGI (15 lbs.)
2016 Hand Portable Imager + Spectrometer
10x less size and weight

Versatile Global Commercial Product

Fulcrum (8-9 lbs.)
2018 Hand Portable Spectrometer

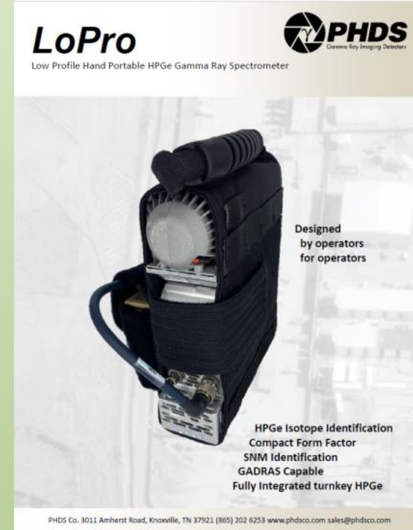
Specialty Operations Products

LoPro (8-11 lbs.)
2020 Specialty Spectrometer

From *Frontiers* of Nuclear Physics to *Frontlines* of Nuclear Security

PHDS Co. now manufactures and sells 4 HPGe products

PHDS
Gamma Ray Detectors



Detect, Identify, Locate, Quantify

Detect, Identify, Quantify

Detect, Identify Special Apps

Radiochemistry, Rare Isotopes

PHDS
Gamma Ray Detectors

Brock Roberts
Electrodynamic

PHDS
Gamma Ray Detectors

PHDS Co. supports 4 products

+

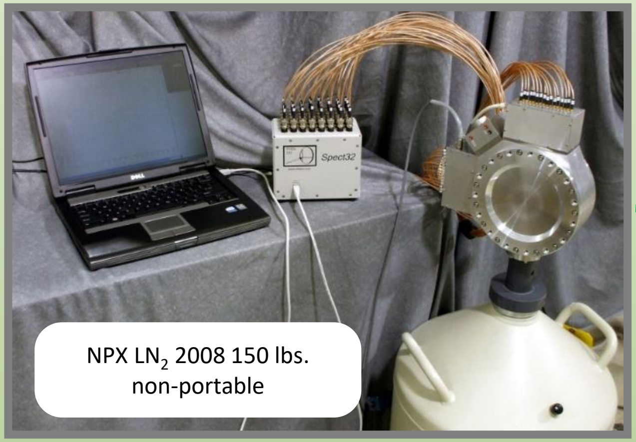
All Critical HPGe manufacturing and R&D capabilities

PHDS Co. Organic path to vertical integration and products:
Sponsored research, sales and persistence

DOE NP Grants, Sales and Product Performance

Germanium System Evolution at PHDS Co.

PHDS
Gamma Ray Detectors



NPX LN_2 2008 150 lbs.
non-portable

NPX-M no LN_2 2009
70 lbs. non-portable

GeGI-1 2010
55 lbs.
Movable

GeGI-3 2013
33 lbs. Transportable

GeGI-4 2015
28 lbs. Personnel Portable

GeGI-5 2016-17
15 lbs. Hand Portable

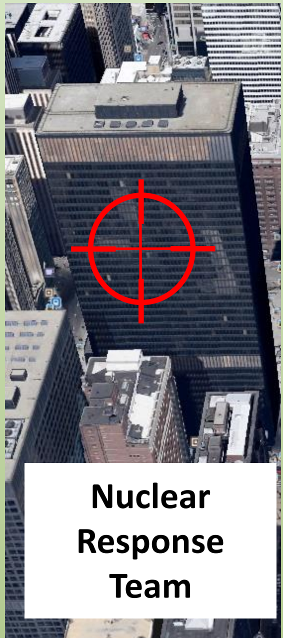
Fulcrum 2017-19
7-8 lbs. Hand Portable

LoPro 2020
9-10 lbs. Hand Portable

Gamma-ray Detection and Imaging Applications

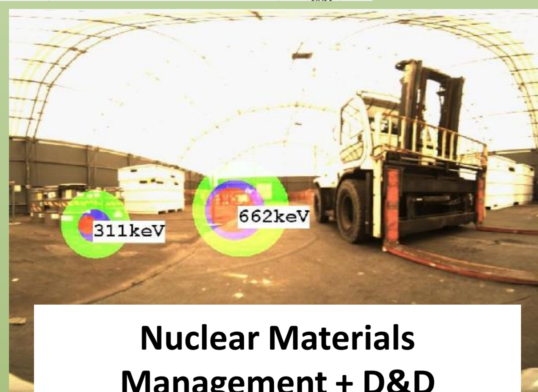
PHDS
Ray Detectors

Nuclear Security

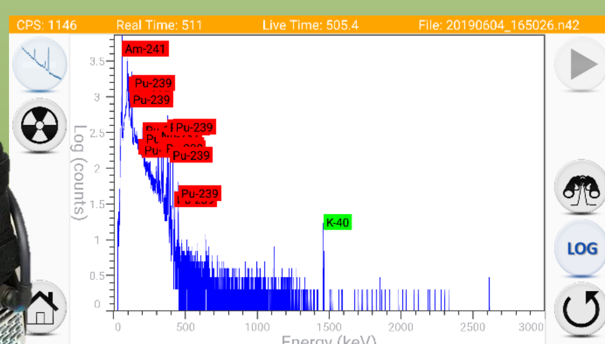


Nuclear Response Team

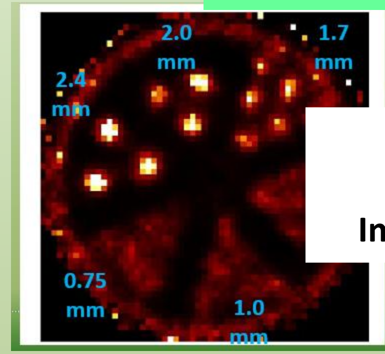
CBRN Team



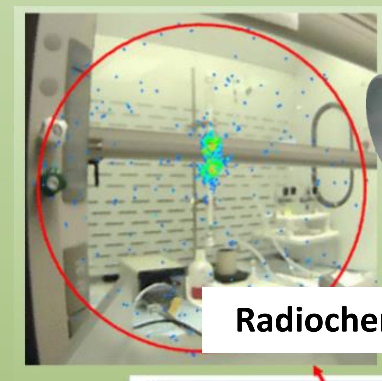
Nuclear Materials Management + D&D



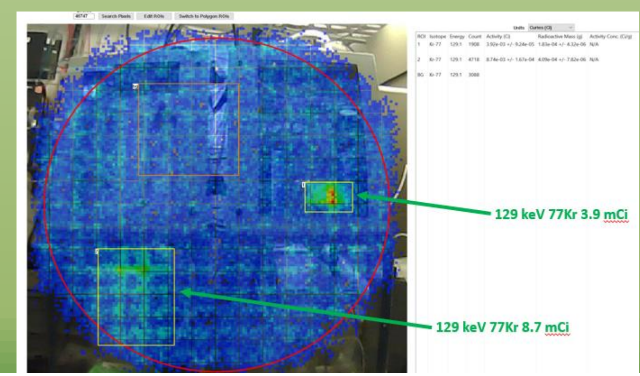
Research



Nuclear Medicine Imaging R&D



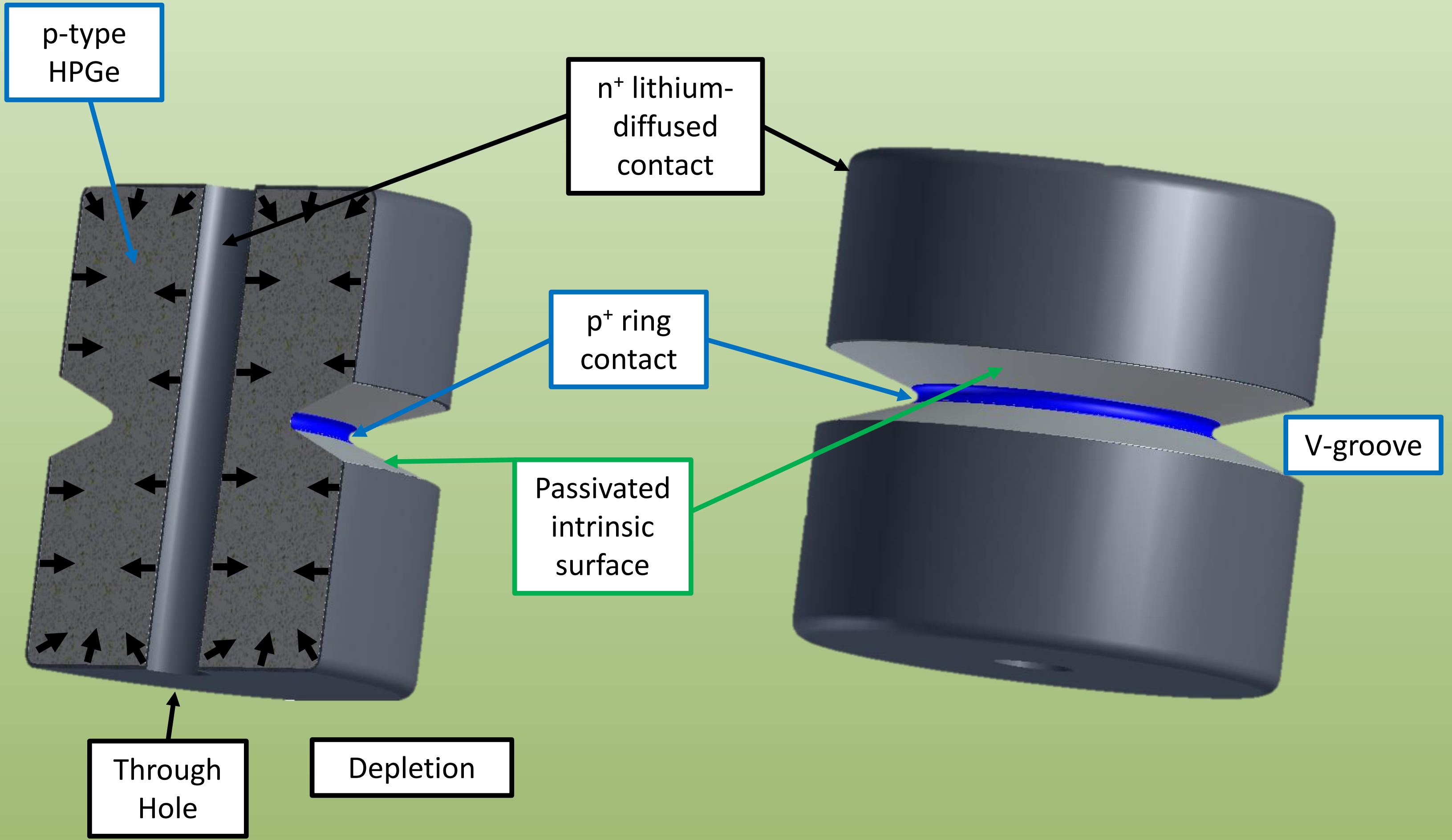
Radiochemistry



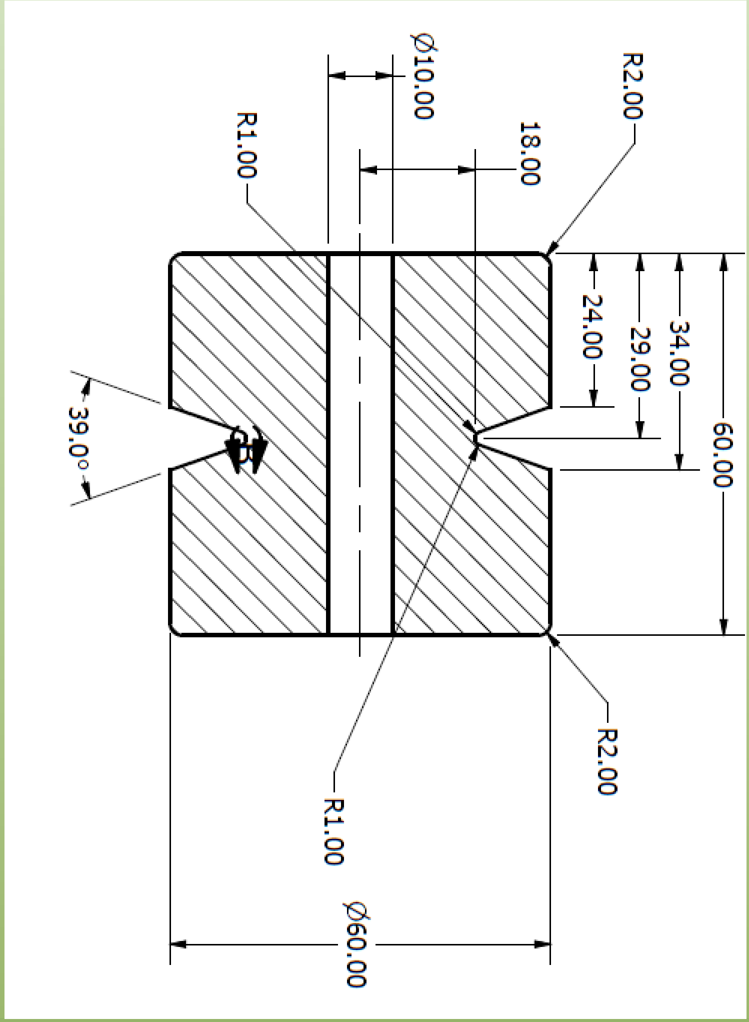
R&D Isotope production / harvesting

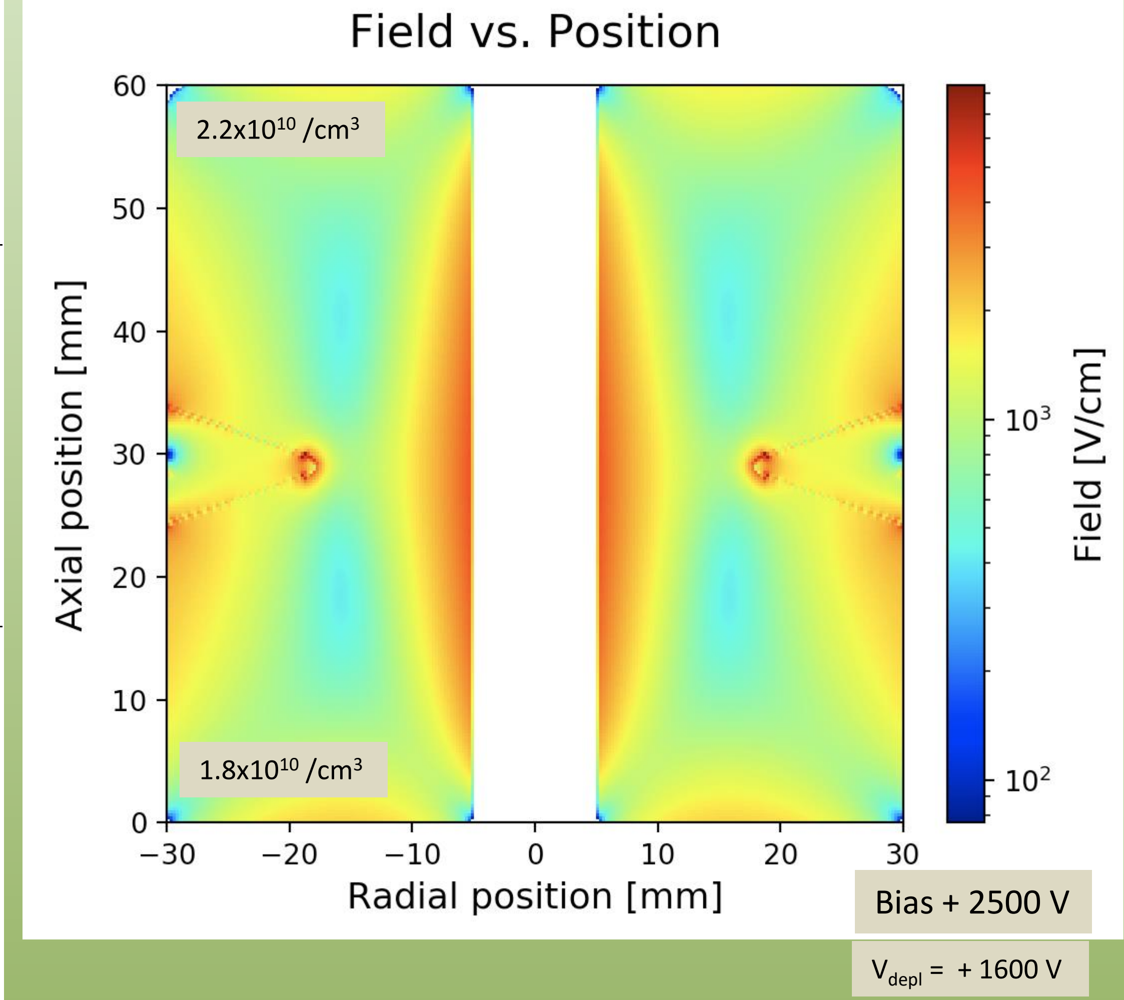
Ring Contact Detector (RCD) Concept – David Radford

PHDS Gamma Ray Detectors

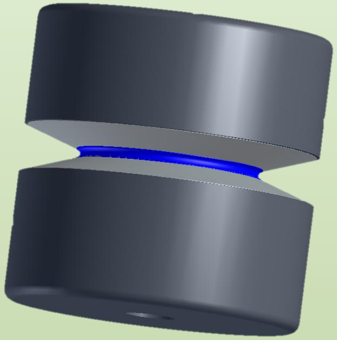


Ring Contact Detector (RCD) Concept – David Radford





Electrostatics Calculations show scalability up to <u>8 kg of depleted HPGe</u>



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Gamma Ray Detectors

RCD Features

Largest Mass

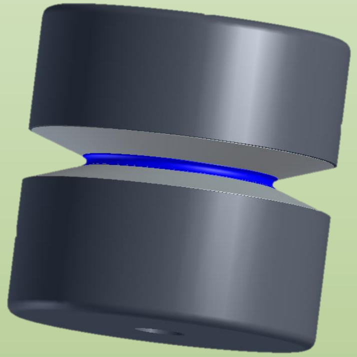
Fewest Detectors per kg of Ge

Lowest background (connections, mounting etc.)

Majorana + LEGEND

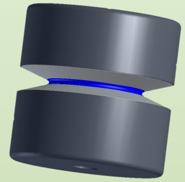
High efficiency – R&D and Counting Labs

RCD Phase II Experimental Plan – 3 parts
Develop the 3 key enablers to demonstrate RCD



1. **Mechanical Preparation**
   - Diamond Grinding
   - Polishing
   - V-Groove
   - Through Hole
2. **Semiconductor Detector Processing**
   - Etch
   - Lithiation
   - Boron Implanation
   - Intrinsic Surface Passivation
   - Testing
3. **Crystal Growth**
   - Uniformity
   - Length of HPGe Region
   - Charge Collection

1. Mechanical Preparation



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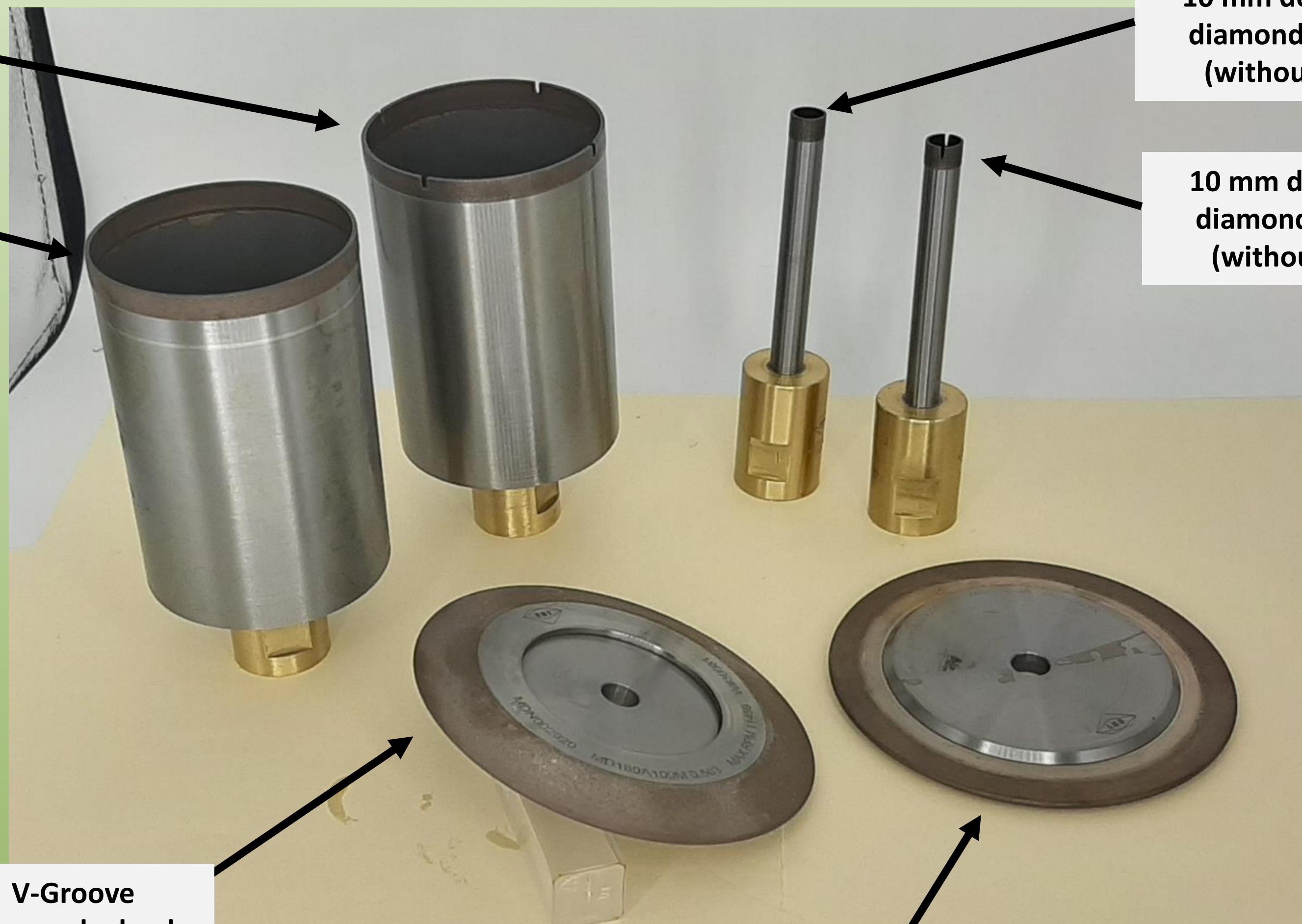
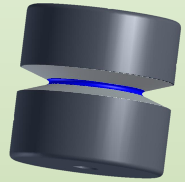
Gamma Ray Detectors



1. Mechanical Preparation
Develop technique



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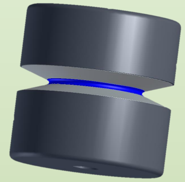
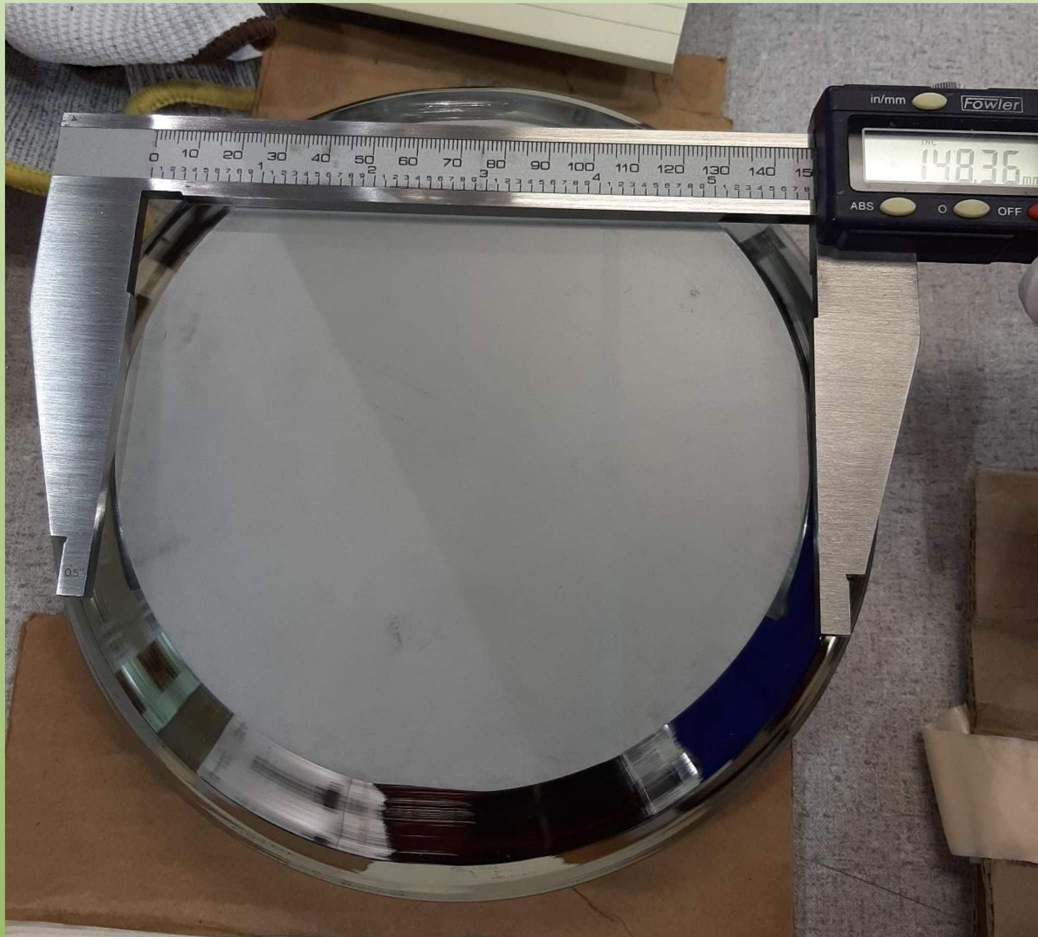
Gamma Ray Detectors

Practice slab of non-detector grade HPGe

1. Mechanical Preparation



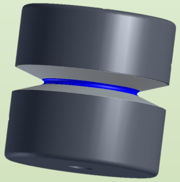
PHDS
Gamma Ray Detectors



60 mm x 60 mm cylinder core-drilled from the slab

Prototype RCD detector cut from a slab of detector-grade HPGe

1. Mechanical Preparation



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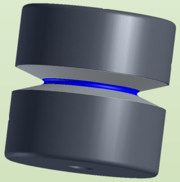
Gamma Ray Detectors

60 mm x 60 mm cylinder
V-Groove cut on lathe

1. Mechanical Preparation



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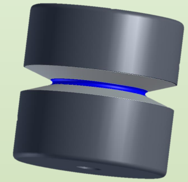
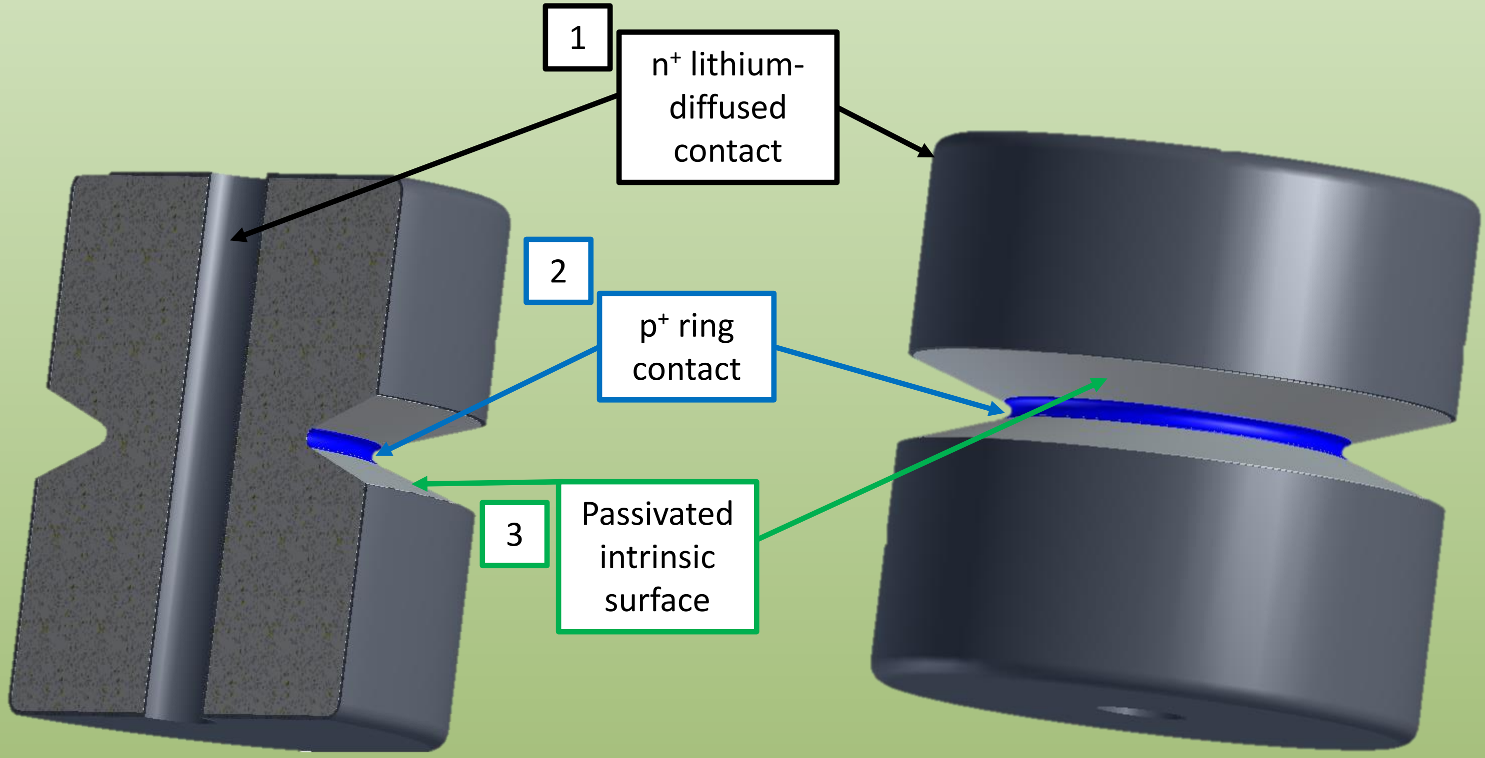
Gamma Ray Detectors

10 mm hole bore

and polish - ready

2. Semiconductor Detector Processing
Steps Li, p+, passivation - geometry





2. Semiconductor Detector Processing
Chemical Etch

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After Chemical Etch 3:1 $HN0_3$: HF

After Chemical Etch 3:1 $HN0_3$: HF

2. Semiconductor Detector Processing
Lithium

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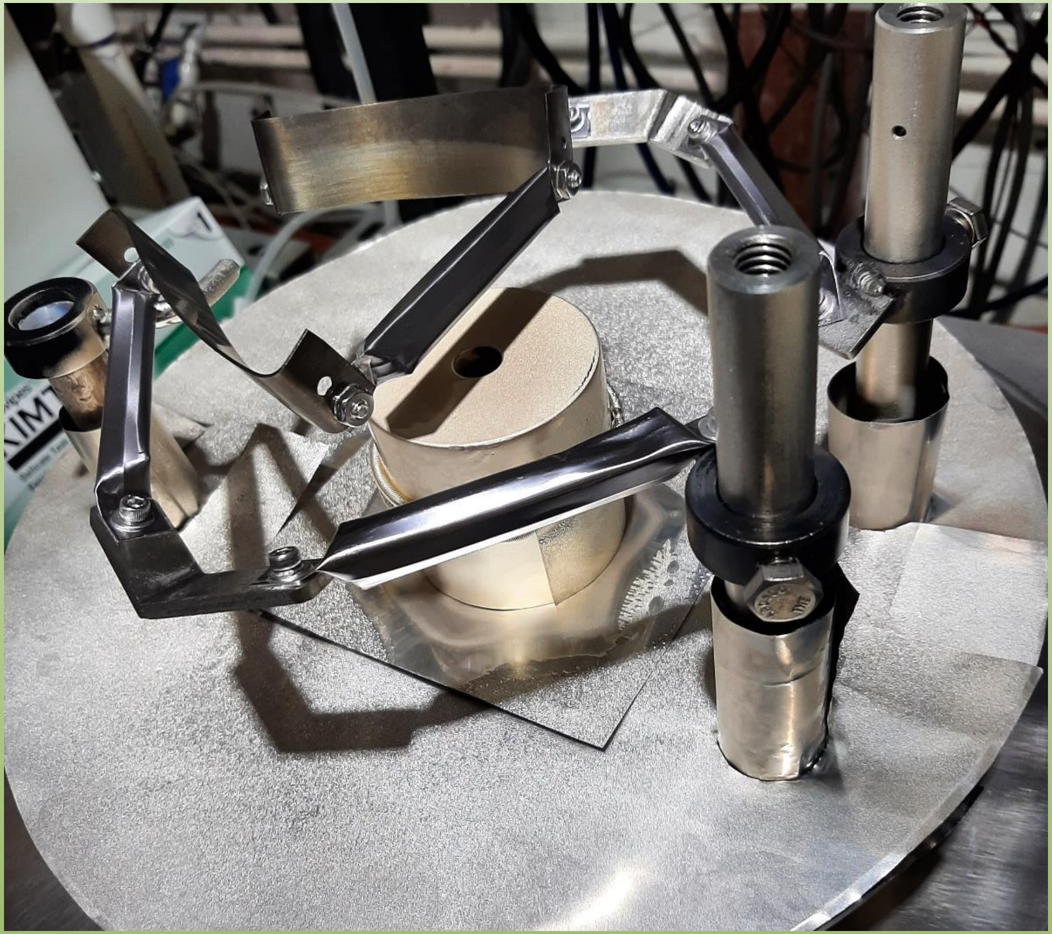
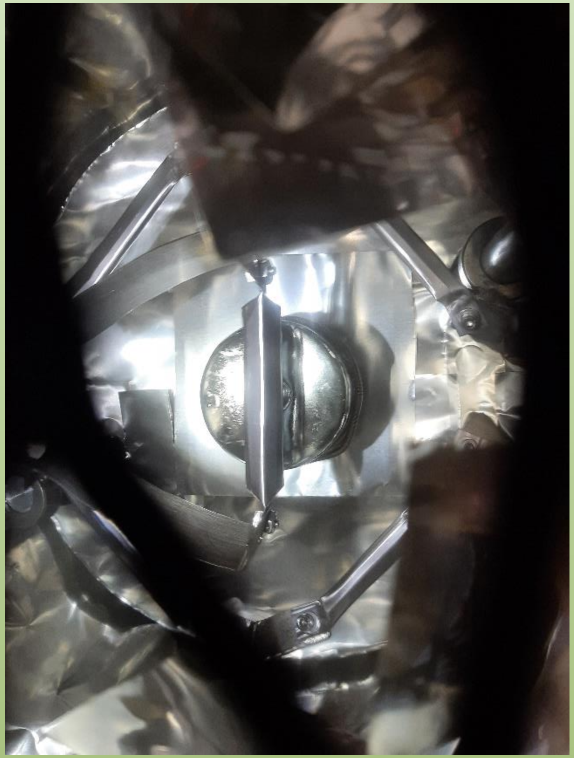
Li thermal diffusion system



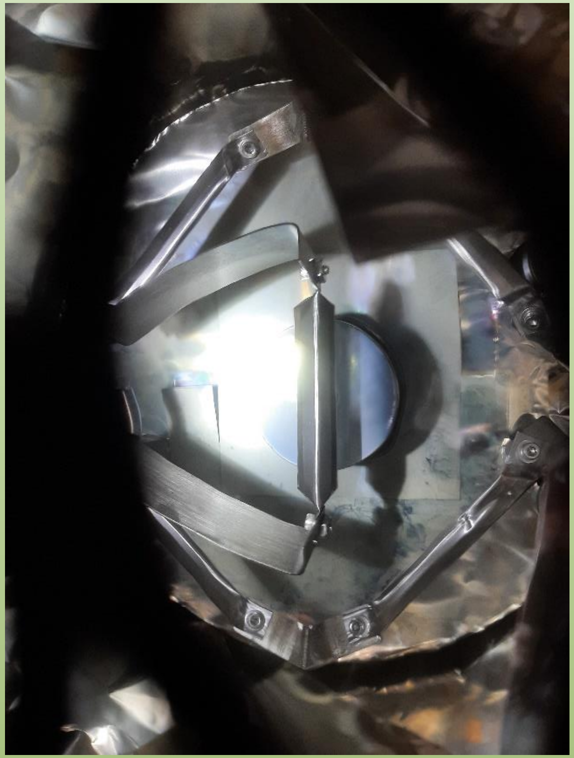
Special 5-boat array to accommodate through hole
Evaporate Li, then heat to 170C for 2 hours in vacuum

2. Semiconductor Detector Processing
Lithium evaporation and diffusion

Gamma Ray Detectors



0 minutes



1.5 minutes

3.0 minutes

2. Semiconductor Detector Processing
Lithium evaporation and diffusion

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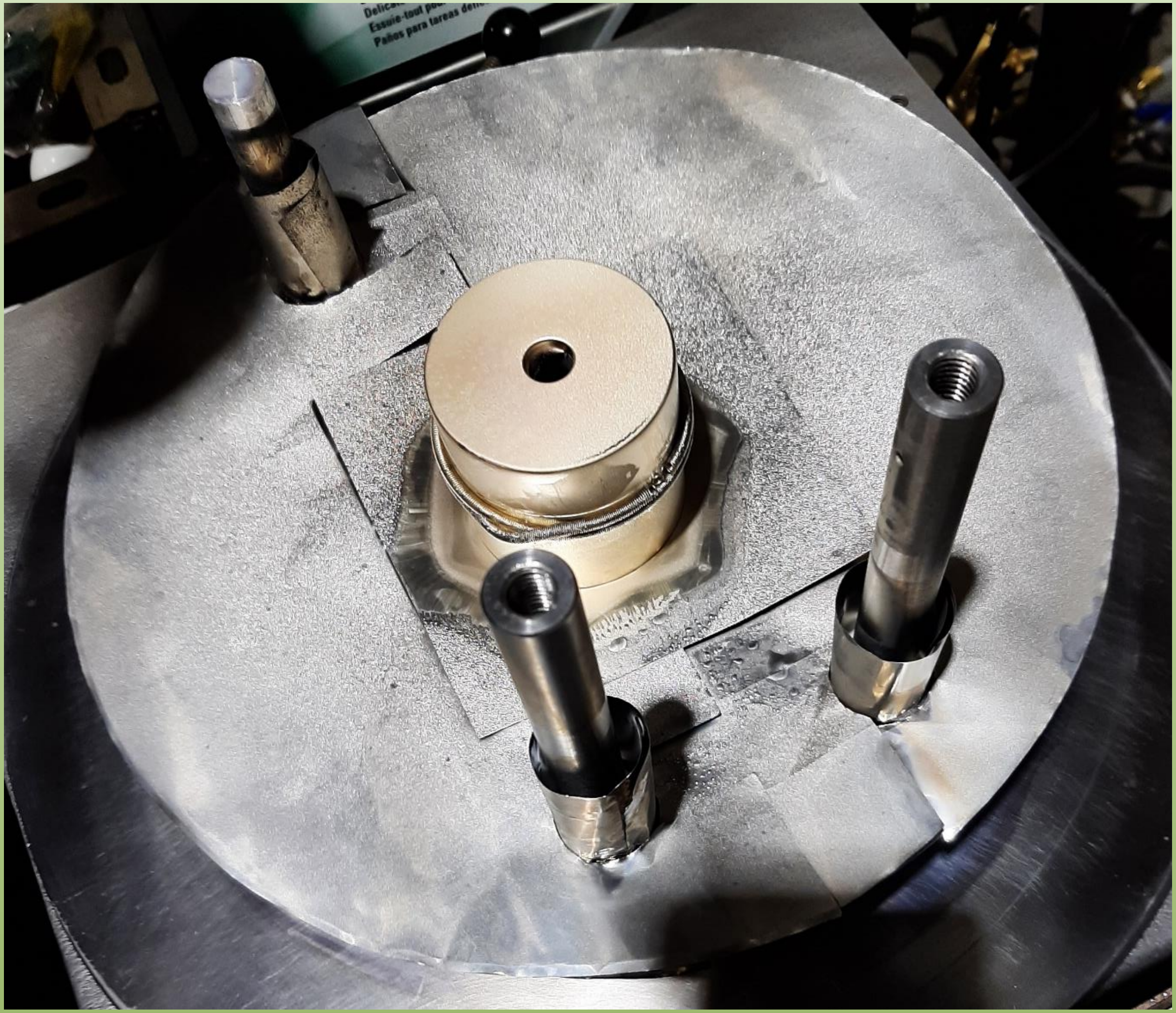

Lithium coating

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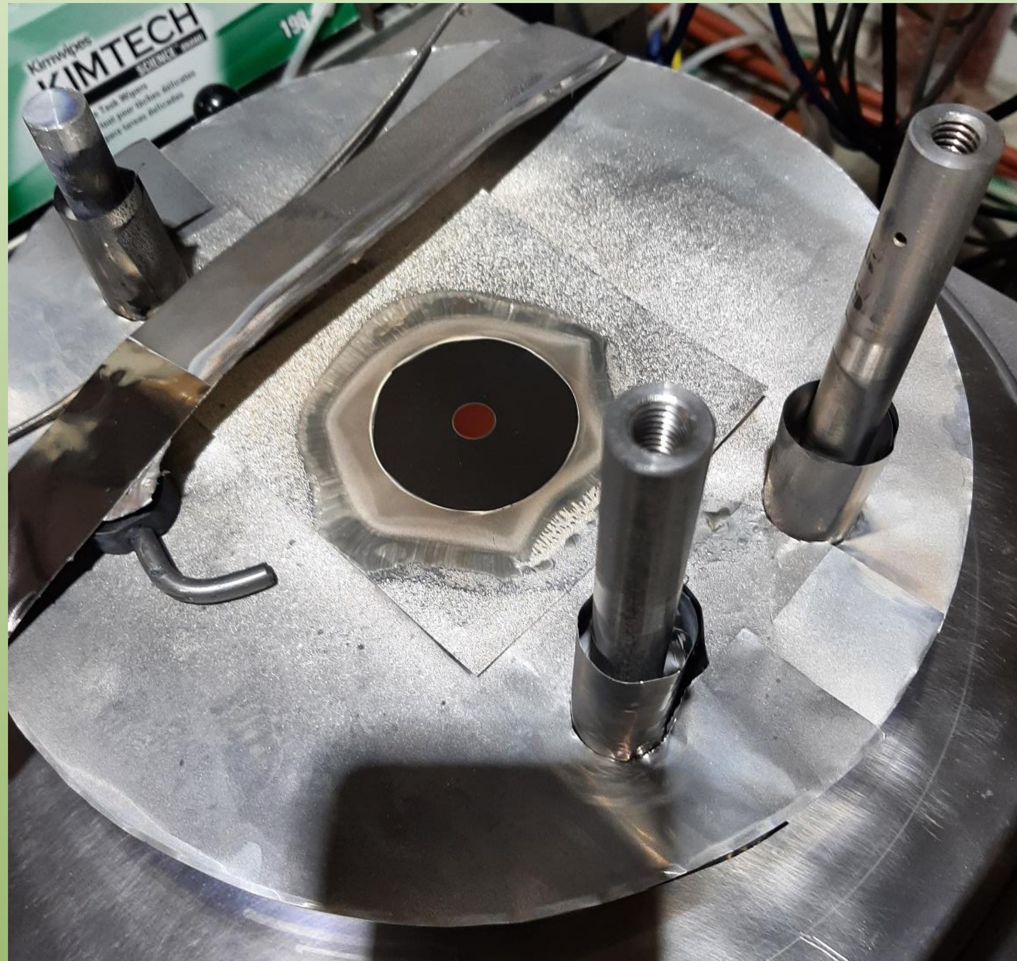
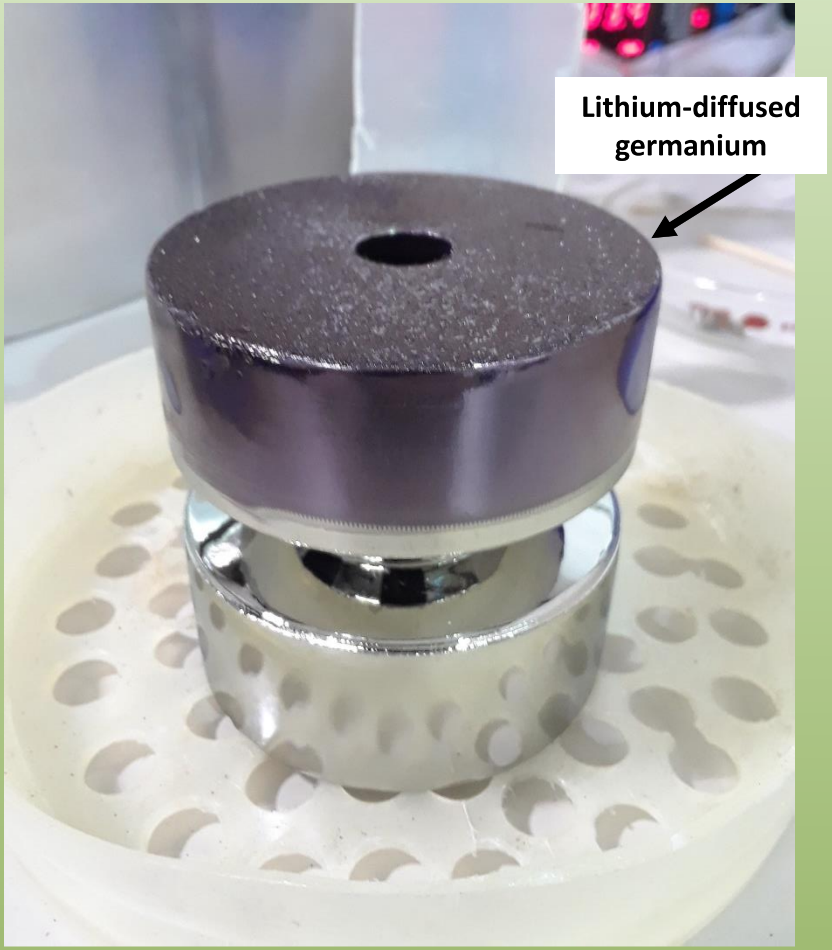
2. Semiconductor Detector Processing
Lithium



5th boat spot on ss foil through the hole

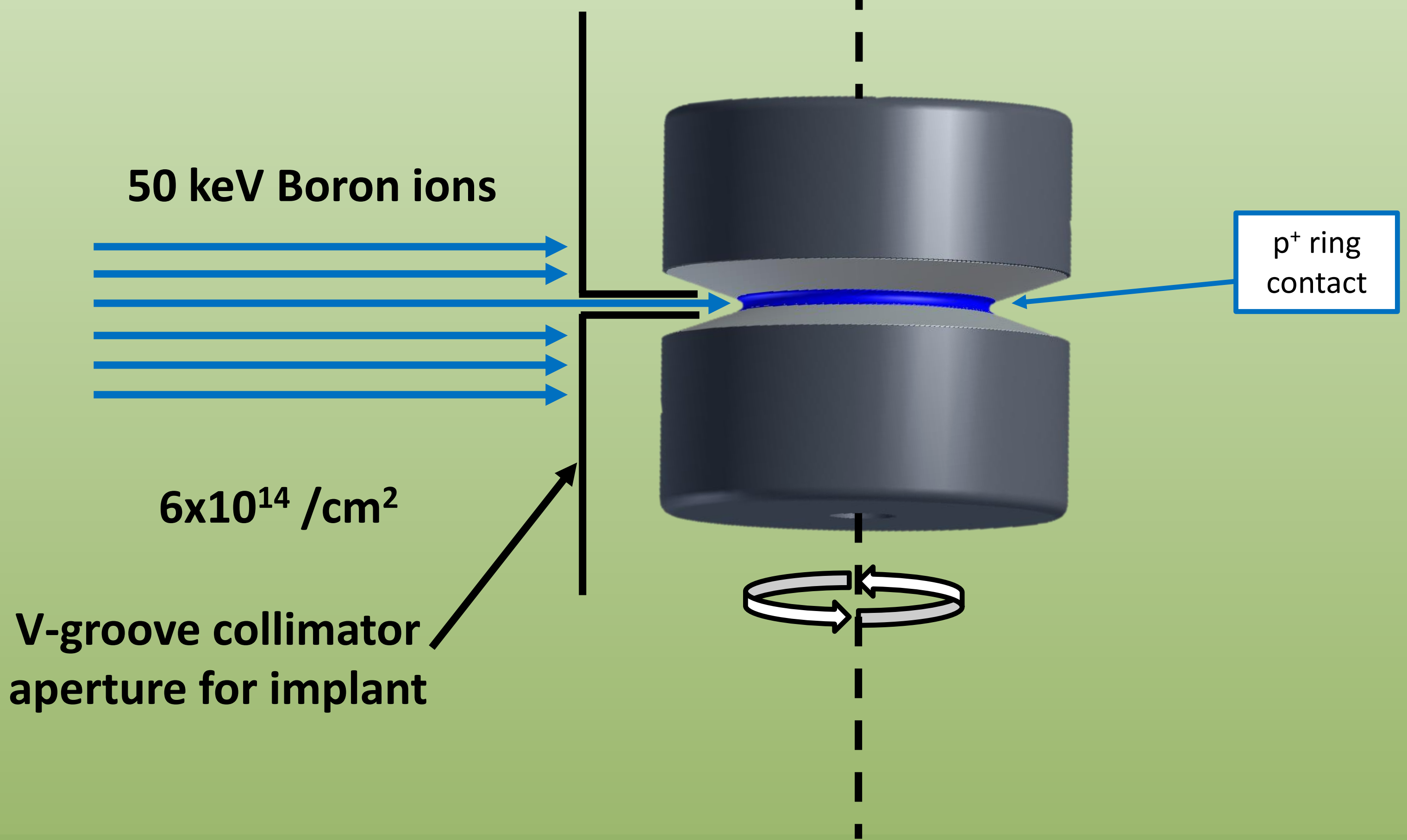
2. Semiconductor Detector Processing
Lithium

ss foil shield with coil spring



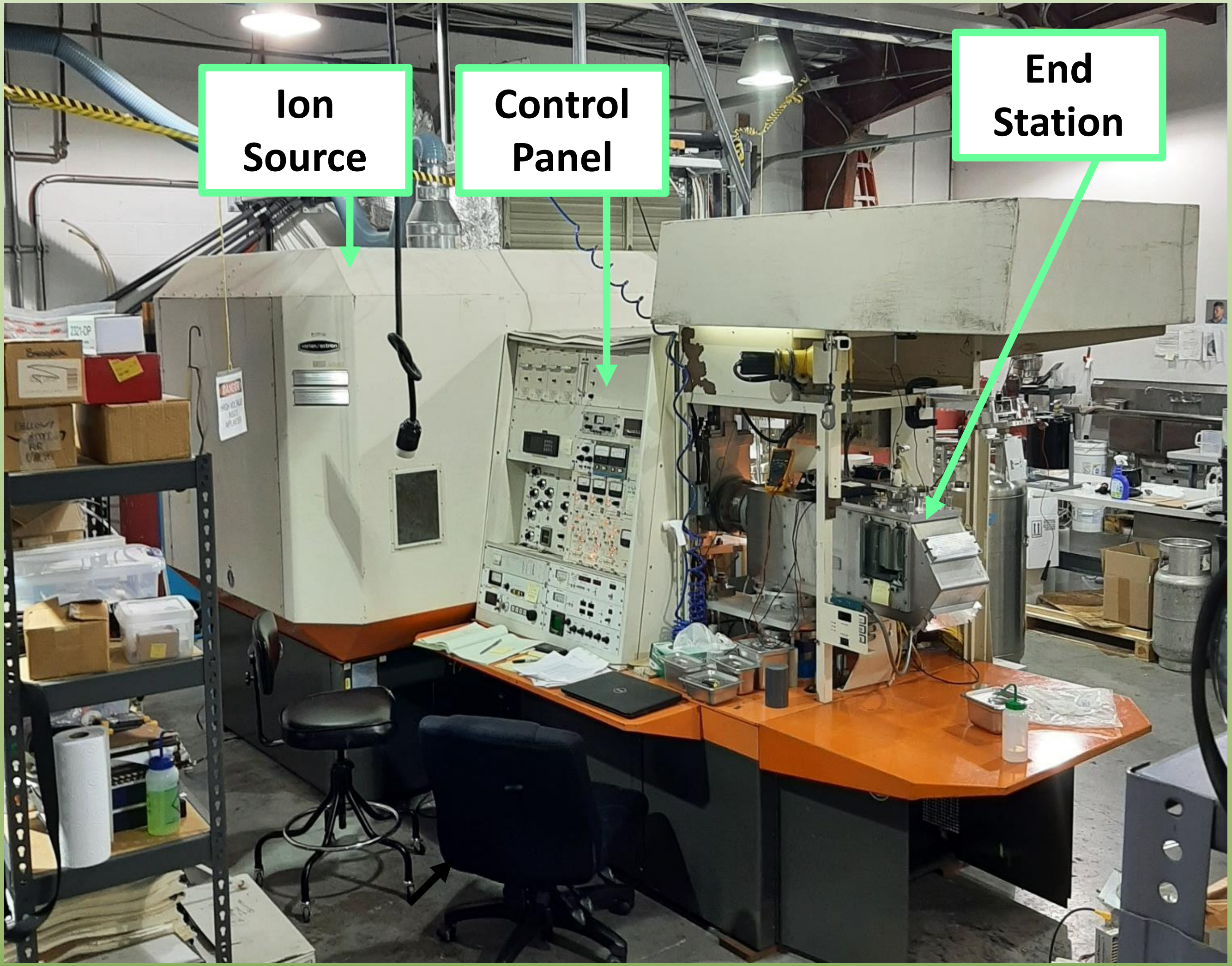
Repeat lithium diffusion with the detector inverted

2. Semiconductor Detector Processing
Boron Implant



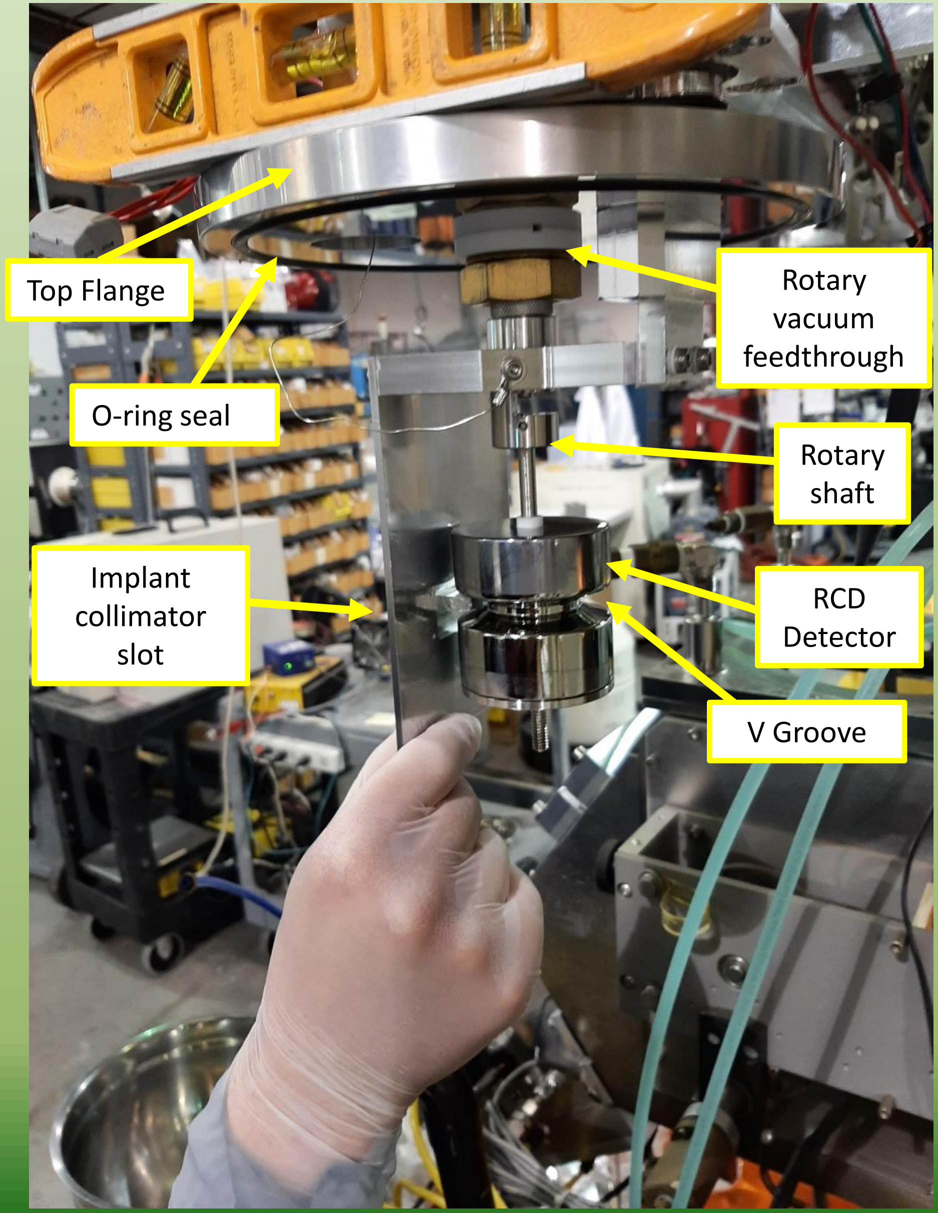
2. Semiconductor Detector Processing

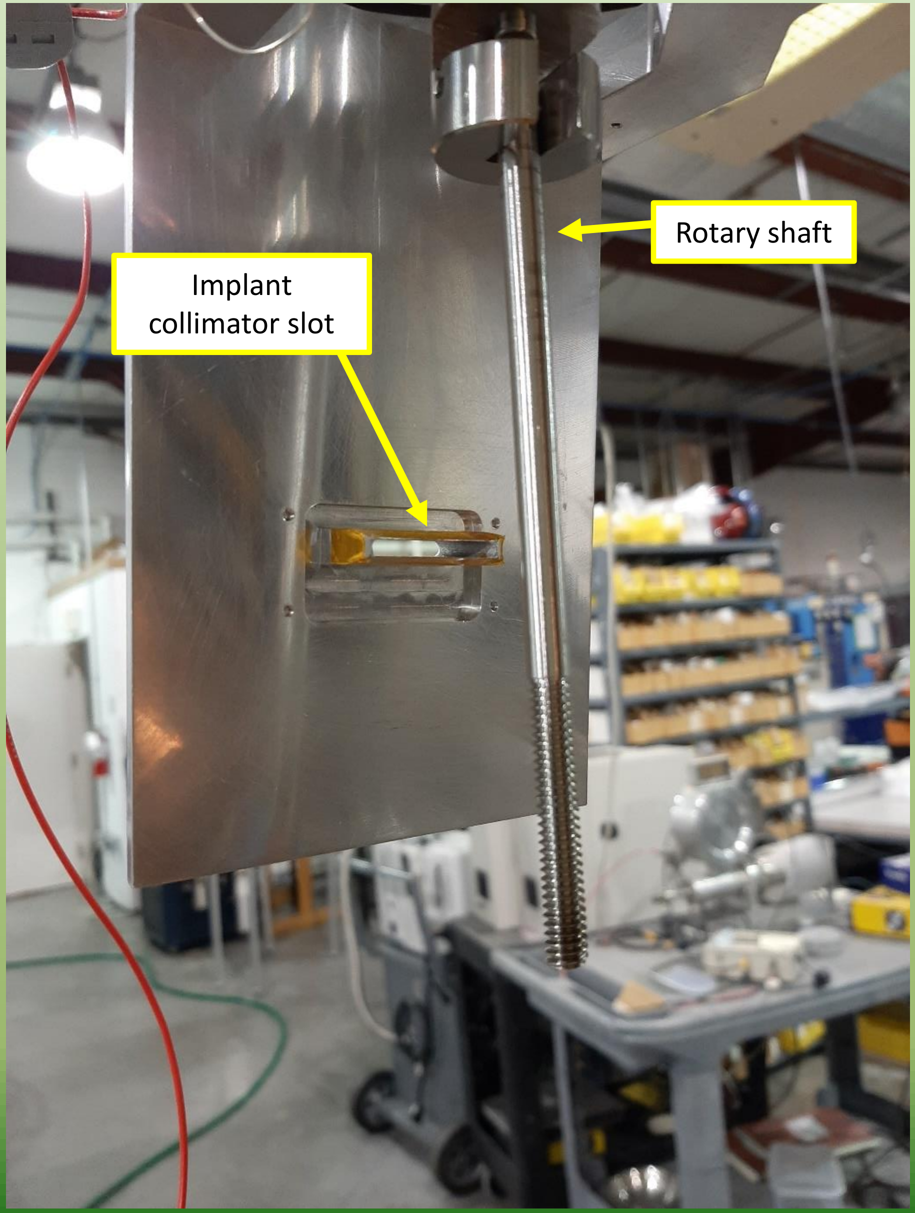
Boron Implant – Ion implantation system



The end station required modification to fabricate the RCD

2. Semiconductor Detector Processing
Boron Implant – RCD End Station





2. Semiconductor Detector Processing
Boron Implant – Rotating detector mount

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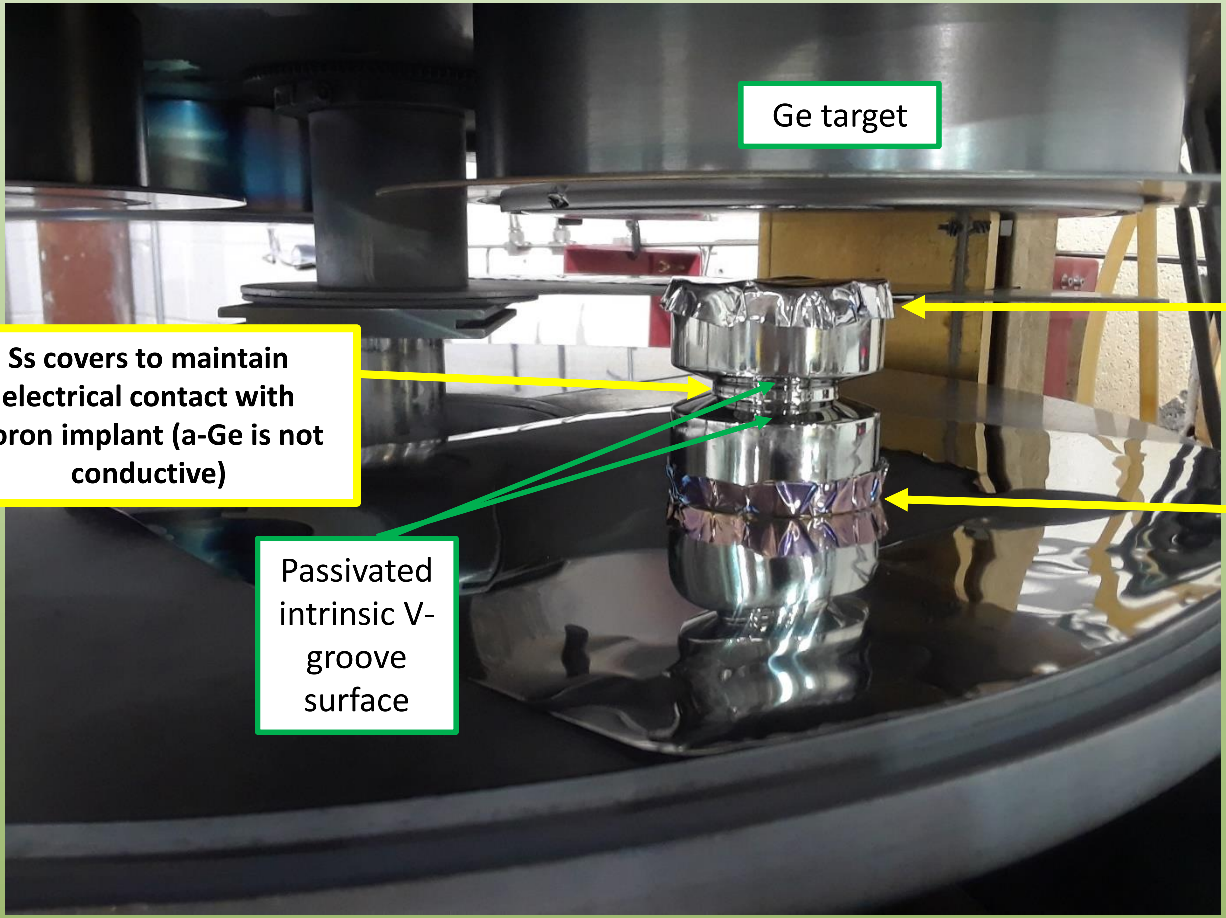
2. Semiconductor Detector Processing
Passivation – amorphous germanium (V-groove)



2. Semiconductor Detector Processing
Finished detector

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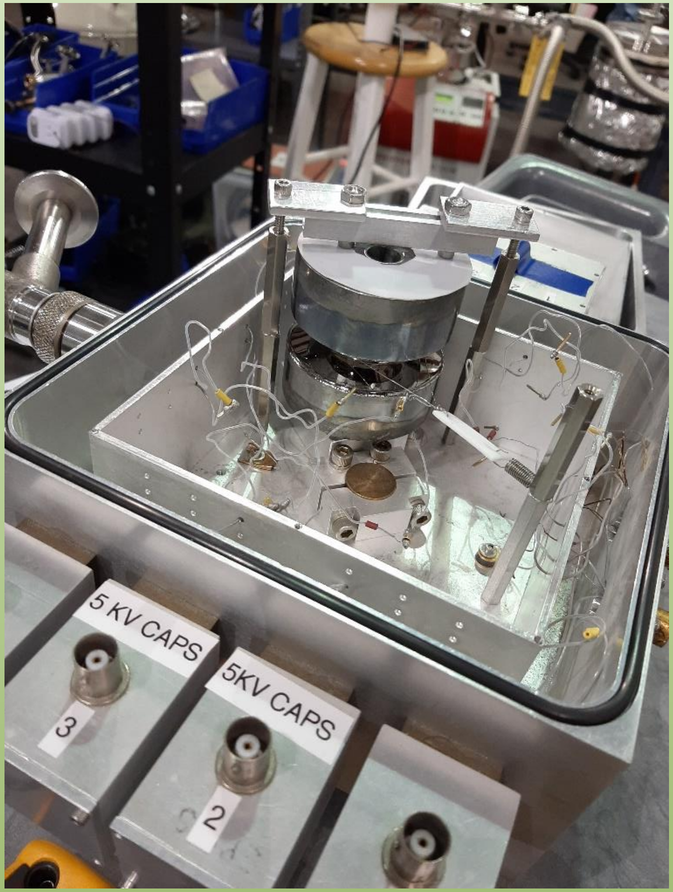
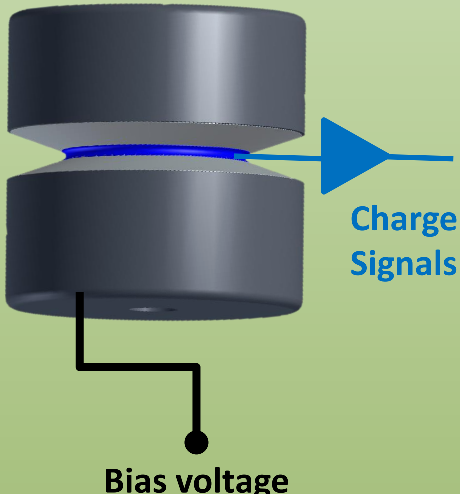
2. Semiconductor Detector Processing
Finished detector - testing



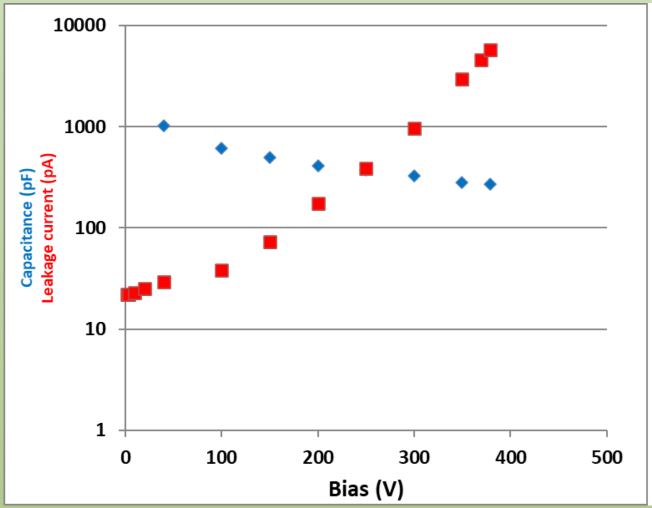
Mounted in a four-place test cryostat

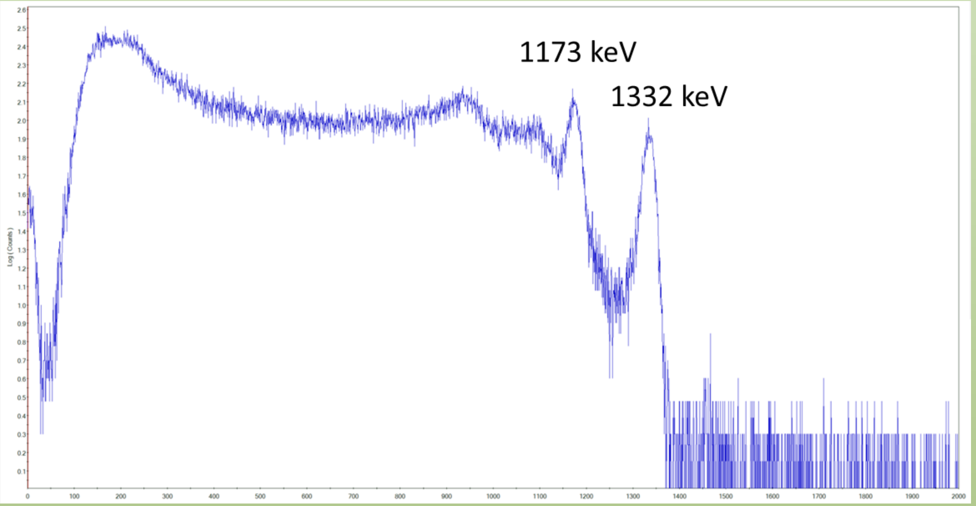
Spring loaded wire loop on ring contact.
This is the signal contact



2. Semiconductor Detector Processing
RCD detector testing

Gamma Ray Detectors

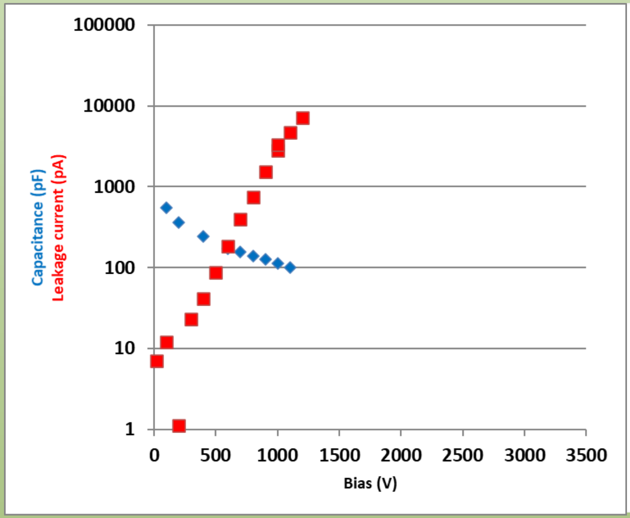


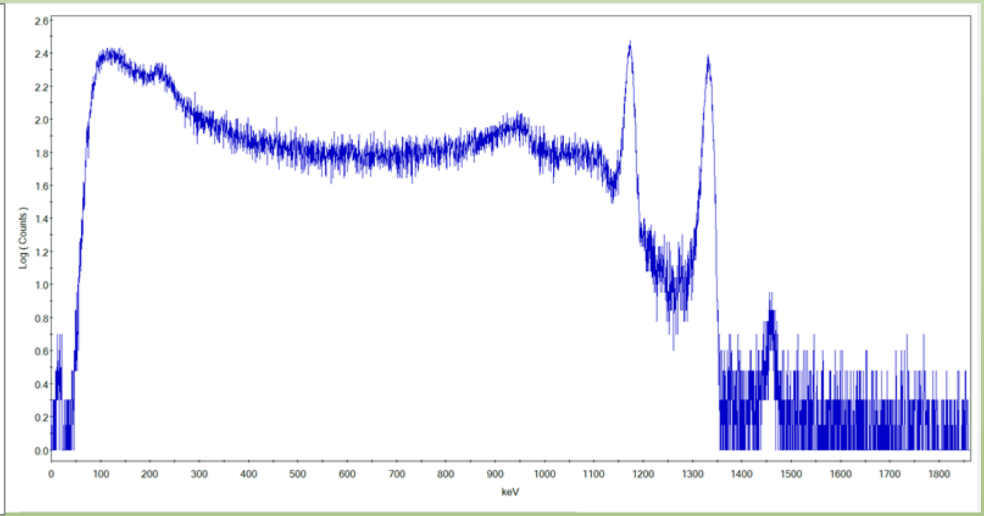


An early test shows the detector taking 400 V.
A noisy spectrum was measured at 300 V.

2. Semiconductor Detector Processing
RCD detector testing

-try again





A test shows the detector taking 1200 V.
A noisy spectrum was measured at 1000 V.

2. Semiconductor Detector Processing
RCD detector testing
and again.

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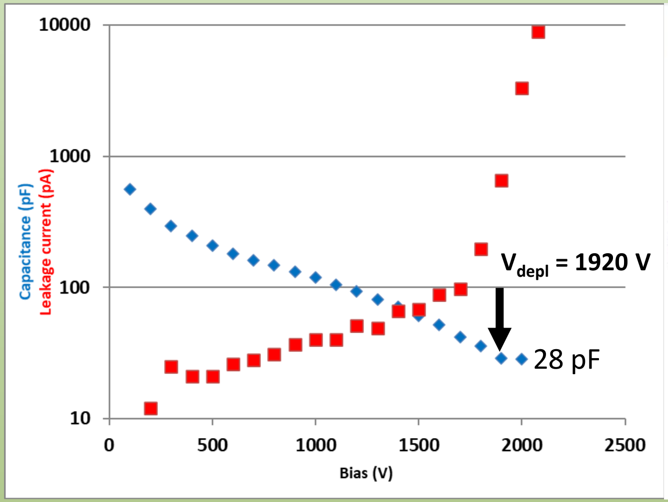
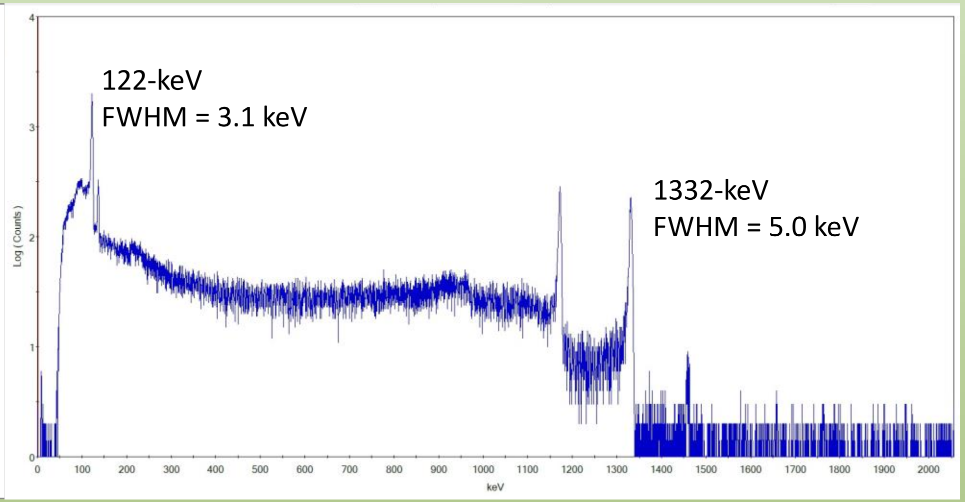




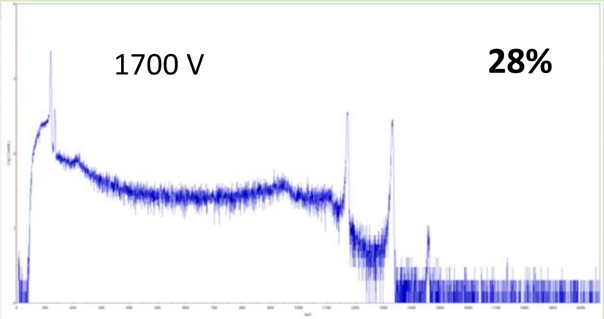
A more recent test shows the detector taking 2200 V.
A spectrum was measured at 1800 V. V_{depl} = 1920 V.

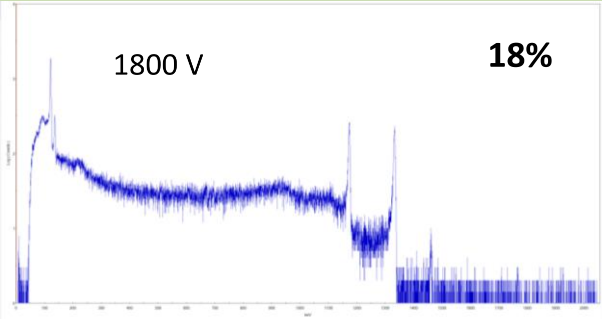
Progress points

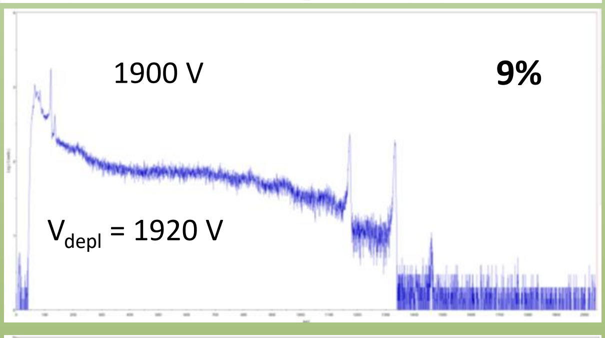
- **Depleted Detector – 1920 V is reasonable**
- **Capacitance is reasonable**
- **Spectroscopy is so – so**
  - **Working on this now…**

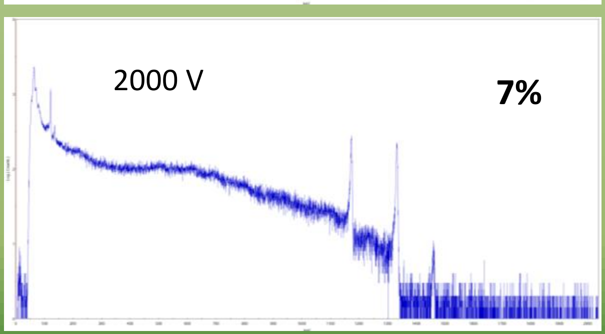
Semiconductor physics observation

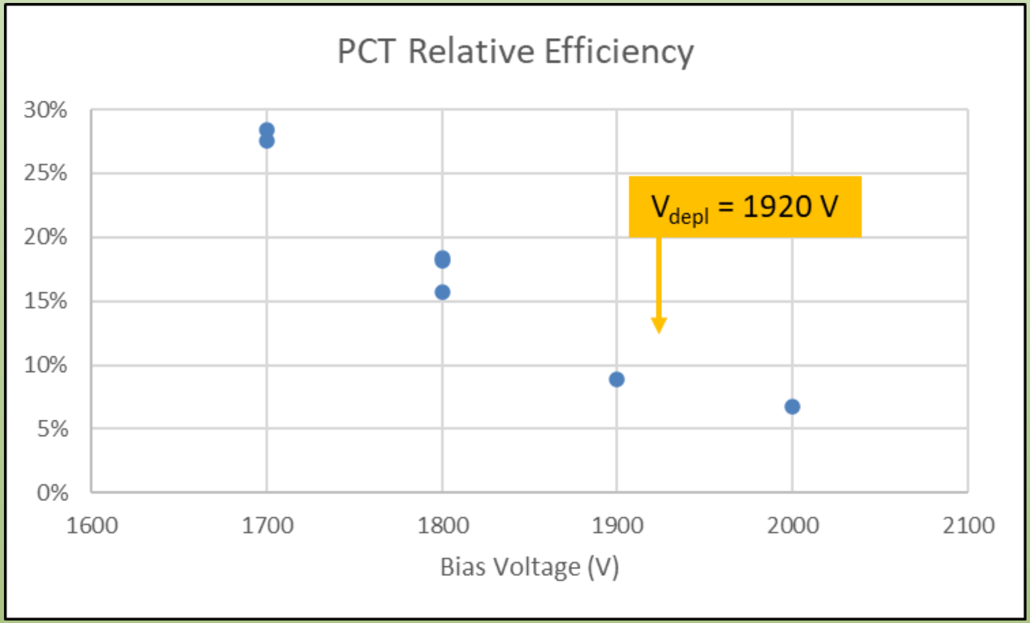
PHDS Gamma Ray Detectors





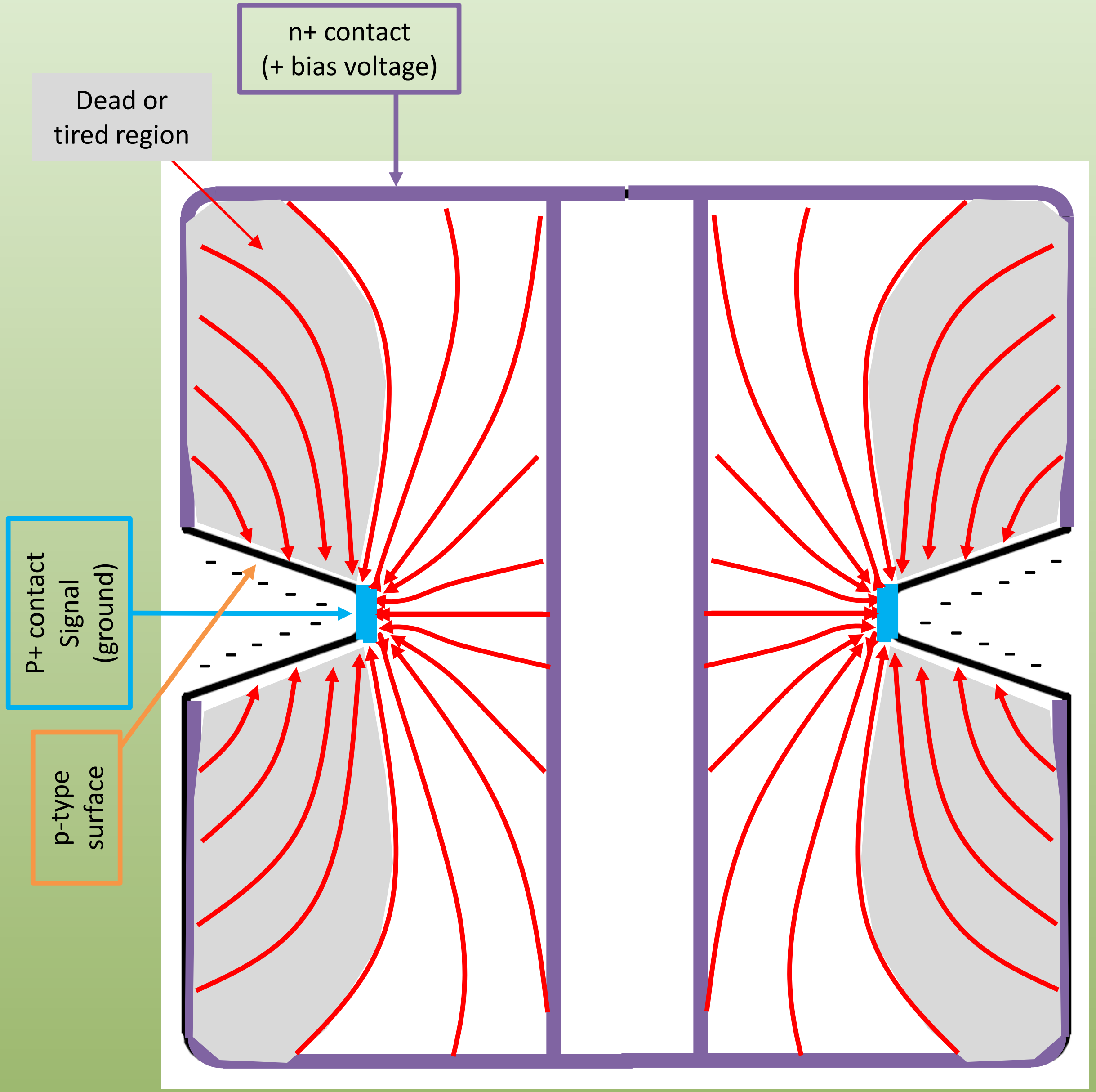






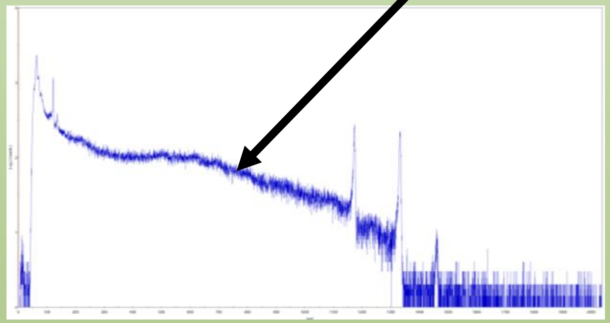
The full-energy 1332-keV peak efficiency decreases dramatically with increasing bias near V_{depl} – an interesting result

PHDS Gamma Ray Detectors

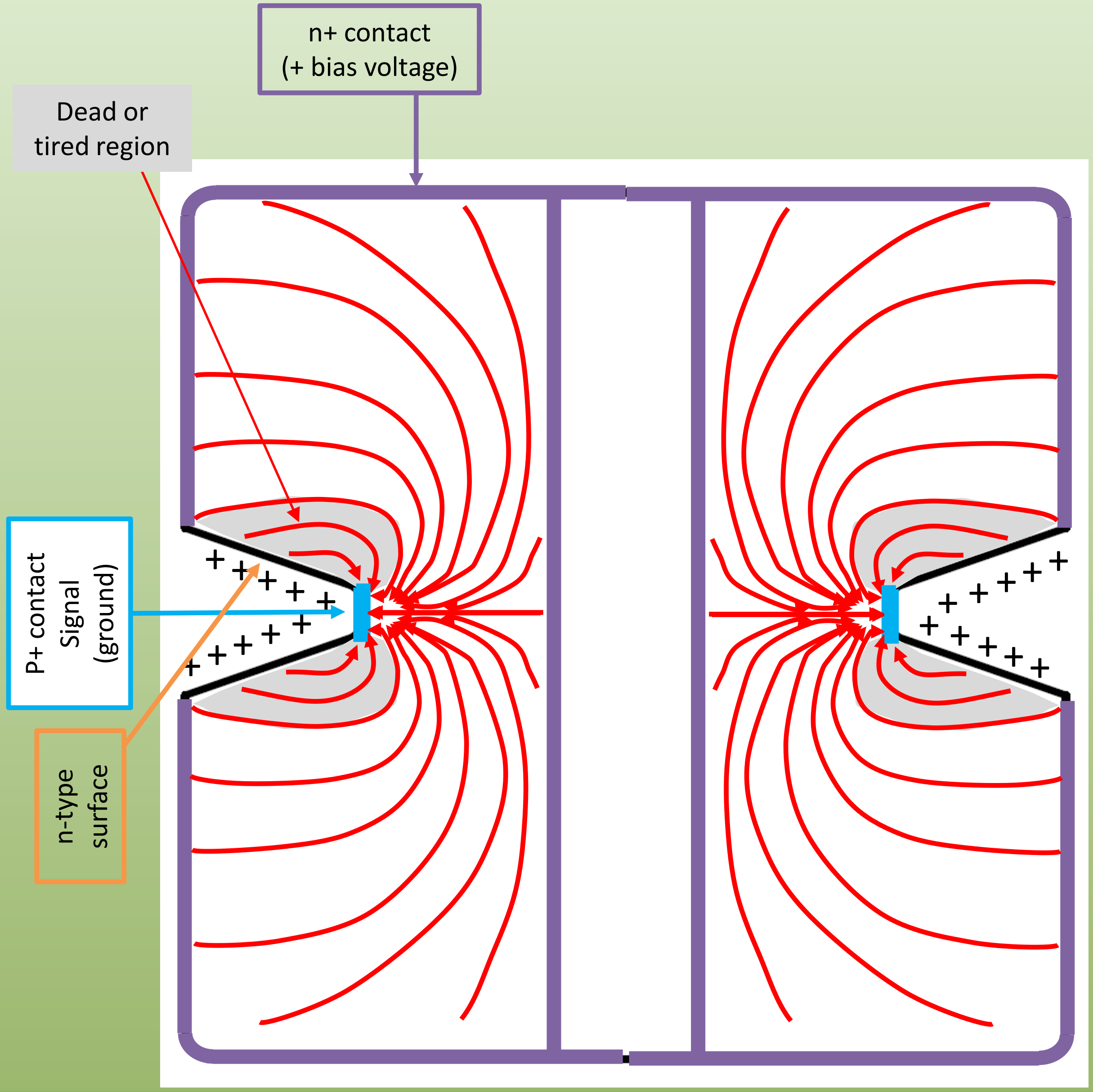


p-type surface channel

Any holes reaching the p-type intrinsic surface are effectively stopped and contribute little (if any signal)



A p-type surface channel affects a significant volume of the RCD detector



n-type surface channel

An n-type surface channel would affect a smaller volume of the RCD detector

Currently working to move the SC from p to n (or ideally i)

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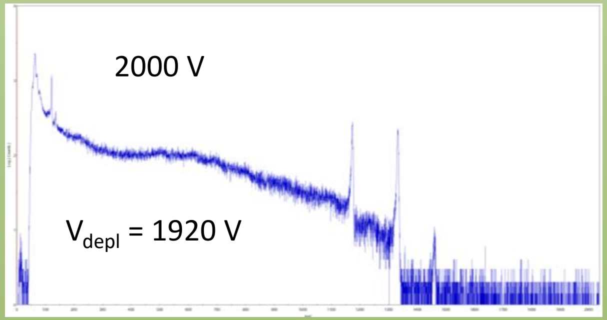
Gamma Ray Detectors

RCD Phase II

1. Mechanical Preparation

2. Semiconductor Detector Processing

3. Crystal Growth



Thank you