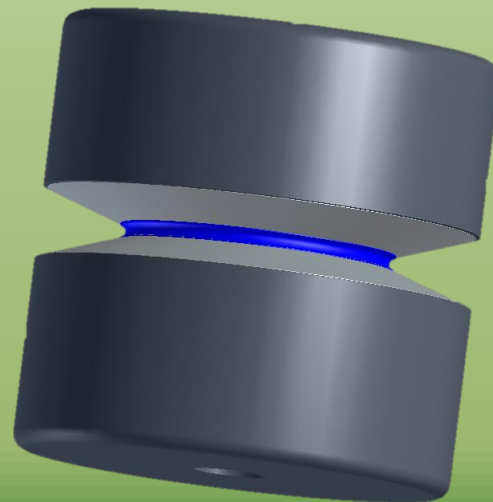


LARGE VOLUME RING-CONTACT HPGE DETECTORS (RCD)

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



Science Experiment

NPX (150 lbs.)
2008 Laboratory

Versatile Global Commercial Product

Versatile Global Commercial Product

Specialty Operations Products

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

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

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

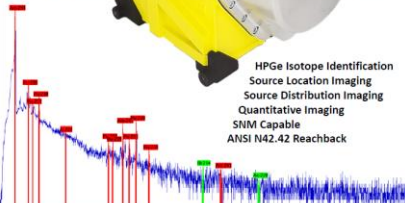


GeGI

Germanium Gamma-Ray Imaging HPGe Spectrometer



HPGe Isotope Identification
Source Location Imaging
Source Distribution Imaging
Quantitative Imaging
SNM Capable
ANSI N42.42 Reachback

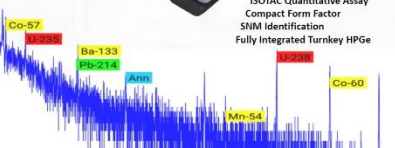


Fulcrum

Hand Portable HPGe Gamma Ray Spectrometer



HPGe Isotope Identification
ISOTAC Quantitative Assay
Compact Form Factor
SNM Identification
Fully Integrated Turnkey HPGe



LoPro

Low Profile Hand Portable HPGe Gamma Ray Spectrometer



Designed by operators for operators

HPGe Isotope Identification
Compact Form Factor
SNM Identification
GADRAS Capable
Fully Integrated turnkey HPGe

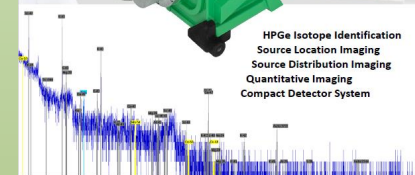
PHDS Co. 3011 Amherst Road, Knoxville, TN 37921 (865) 202 6253 www.phdco.com sales@phdco.com

NP Imager

Nuclear Physics - Radiochemistry Imaging Spectrometer



HPGe Isotope Identification
Source Location Imaging
Source Distribution Imaging
Quantitative Imaging
Compact Detector System



GeGI



GeGI Specifications:	33 lbs. (8.8 kg)
Weight (Detector)	10.5" x 8.5" x 5.5" (26 cm x 21 cm x 14 cm)
Dimensions (Detector)	3 hrs internal (hot swappable), 6 hrs external
Power supply	500-240 VAC, 50/60 Hz
User maintenance	None
Energy resolution	FWHM @ 1.1 MeV (13.3 keV) @ 400 K
Gamma-ray Compton imaging field of view	400 (SNM)
Optical camera field of view	2x (SNM)
Imaging range field of view	10"
Imaging range	(30 cm - 10' meters)
Secondary: 2x 10" ²³⁵ Pu or 2 meter (3.3 m) ²³⁵ Pu, 10 (400 K)	
40" line (optional)	8.7 m (x) x 1 m (38.2 kg) @ 400 K
Location Imaging Time	30 sec @ 1.3 sec (Compton image)
Location Imaging Time	300 KHz @ 1.3 sec (Compton image)
Response rate capacity	200 KHz @ 1.3 sec (Compton image)
Energy range Compton imaging (200 KHz)	30 keV - 3.5 MeV (22 MeV option)
Energy range Compton imaging	100 keV - 3.5 MeV
Energy range Compton imaging	30 keV - 3.5 MeV
Energy range Compton imaging	100 keV - 3.5 MeV
Isotope library	400 isotopes (auto detect or user selected)
Isotope identification	37 frequently encountered isotopes
Isotope identification	SNM, NORM, NDM, MED
Isotope identification	80-mm diameter, 1.5 mm thick
HPGe detector crystal dimensions	47 (10") x 70 (2.8")
Active detector volume / area	2 hours
Cool-down time	2 minutes
Detector startup time	1 minute
Tablet	rugged 40" high-angle glove touch screen



2021029
Specifications subject to change

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Fulcrum



Fulcrum Specifications:	7.5 lbs. (3.4 kg) internal battery
Weight	8" x 6" x 6" (20 cm x 15 cm x 15 cm)
Dimensions	24 hrs
Battery life (hot swappable 10-25V)	20-240 VAC, 50/60 Hz
Power supply	None
User maintenance	None
Energy resolution	FWHM @ 1.1 MeV (13.3 keV) @ 400 K
Relative 133Ba efficiency vs. 3" x 3" NaI	20 (30% dead time to 1.5 mSv/h ⁶⁰ Co)
Exposure capacity	40 sec @ 1.3 MeV (22 MeV option)
Energy range Compton imaging (200 KHz)	88 user-selectable isotopes
Energy range Compton imaging	SNM, NORM, NDM, MED, NORM
Energy range Compton imaging	80-mm diameter, 1.5 mm thick
Energy range Compton imaging	400 (SNM)
Isotope library	37 frequently encountered isotopes
Isotope identification	SNM, NORM, NDM, MED
Isotope identification	80-mm diameter, 1.5 mm thick
HPGe detector crystal dimensions	47 (10") x 70 (2.8")
Active detector volume / area	2 hours
Cool-down time	2 minutes
Detector startup time	1 minute
Tablet	rugged 40" high-angle glove touch screen



2021018
Specifications subject to change



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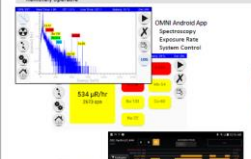
LoPro



LoPro Specifications:	8.3 lbs. (3.8 kg) - battery
Weight	8" x 7" x 7" (20 cm x 20 cm x 18 cm)
Dimensions	4-10 hrs (depends on battery configuration)
Battery life	100-240 VAC, 50-60 Hz
Power supply	None
User maintenance	FWHM @ 1.1 MeV (13.3 keV)
Energy resolution	20 (30% dead time to 1.5 mSv/h ⁶⁰ Co)
Relative 133Ba efficiency vs. 3" x 3" NaI	88 user-selectable isotopes
Exposure capacity	SNM, NORM, NDM, MED, NORM
Energy range Compton imaging (200 KHz)	80-mm diameter, 1.5 mm thick
Energy range Compton imaging	400 (SNM)
Isotope library	37 frequently encountered isotopes
Isotope identification	SNM, NORM, NDM, MED
Isotope identification	80-mm diameter, 1.5 mm thick
HPGe detector crystal dimensions	47 (10") x 70 (2.8")
Active detector volume / area	2 hours
Cool-down time	2 minutes
Detector startup time	1 minute
User interface device	Android Mobile Phone, CMMR or Tablet



2021019
Specifications subject to change



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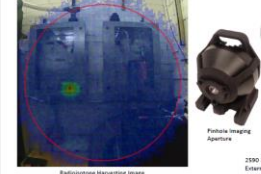
NP Imager



NP Imager Specifications:	33 lbs. (8.8 kg)
Weight (Detector)	10.5" x 8.5" x 5.5" (26 cm x 21 cm x 14 cm)
Dimensions (Detector)	3 hrs internal (hot swappable), 6 hrs external
Battery life	500-240 VAC, 50-60 Hz
Power supply	None
User maintenance	FWHM @ 1.1 MeV (13.3 keV) @ 400 K
Energy resolution	20 (30% dead time to 1.5 mSv/h ⁶⁰ Co)
Relative 133Ba efficiency vs. 3" x 3" NaI	88 user-selectable isotopes
Exposure capacity	SNM, NORM, NDM, MED, NORM
Energy range Compton imaging (200 KHz)	80-mm diameter, 1.5 mm thick
Energy range Compton imaging	400 (SNM)
Energy range Compton imaging	37 frequently encountered isotopes
Energy range Compton imaging	SNM, NORM, NDM, MED
Isotope library	80-mm diameter, 1.5 mm thick
Isotope identification	47 (10") x 70 (2.8")
Isotope identification	2 hours
HPGe detector crystal dimensions	2 minutes
Active detector volume / area	
Cool-down time	
Detector startup time	



2021029
Specifications subject to change



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Detect, Identify, Locate, Quantify

Detect, Identify, Quantify

Detect, Identify Special Apps

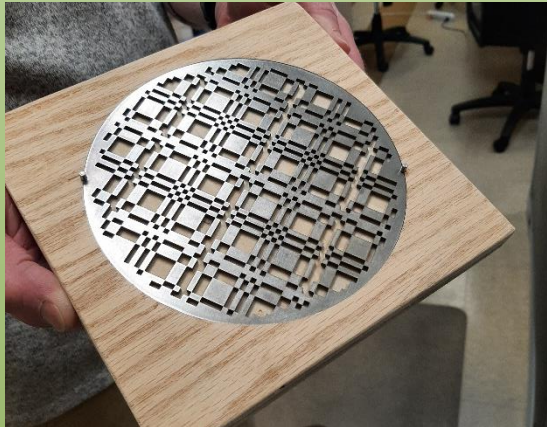
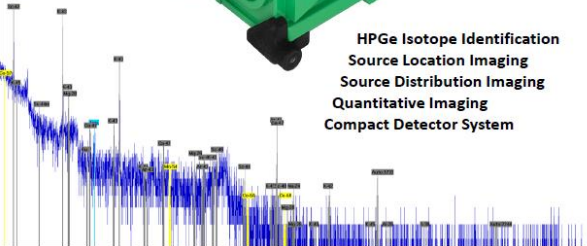
Radiochemistry, Rare Isotopes

NP Imager

Nuclear Physics – Radiochemistry Imaging Spectrometer



HPGe Isotope Identification
Source Location Imaging
Source Distribution Imaging
Quantitative Imaging
Compact Detector System



**Brock Roberts
Electrodynamic**



PHDS Co.
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Knoxville, TN 37934
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www.phdsco.com



GeGI *Gamma*
G

GeGI User Manual

Version: 2019-07-03



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Knoxville, TN 37934
(865) 202-6253
www.phdsco.com



Fulcrum User Manual

Version: 2021-02-18



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LoPro User Manual

Version: 2020-10-29



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NP Imager
Nuclear
Physics
Imager

NP Imager User Manual

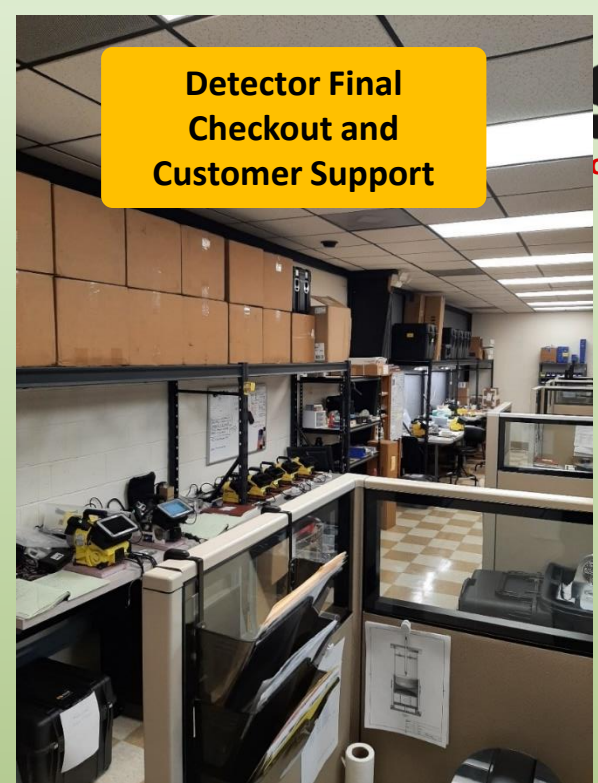
Version: 2020-07-29



PHDS Co. supports 4 products



10,000 ft²
Manufacturing
and R&D Facility
Knoxville, TN



Detector Final
Checkout and
Customer Support



Offices



Manufacturing

All Critical
HPGe
manufacturing
and R&D
capabilities

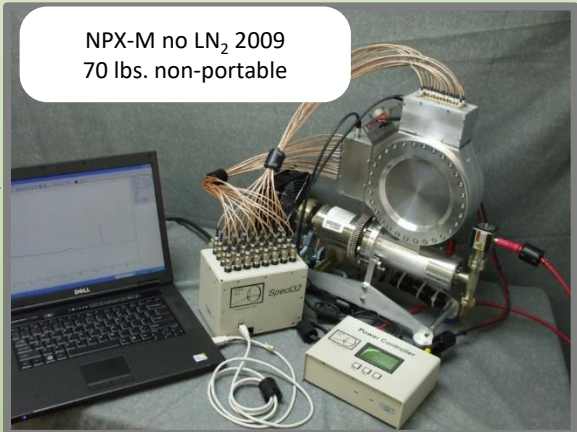
PHDS Co. Organic path to vertical integration and products:
Sponsored research, sales and persistence



Germanium System Evolution at PHDS Co.



NPX LN₂ 2008 150 lbs.
non-portable



NPX-M no LN₂ 2009
70 lbs. non-portable



GeGI-1 2010
55 lbs.
Movable



LoPro 2020
9-10 lbs. Hand Portable



GeGI-5 2016-17
15 lbs. Hand Portable



GeGI-4 2015
28 lbs. Personnel Portable



GeGI-3 2013
33 lbs. Transportable



Fulcrum 2017-19
7-8 lbs. Hand Portable

Gamma-ray Detection and Imaging Applications



Nuclear Security



Nuclear Response Team



CBRN Team

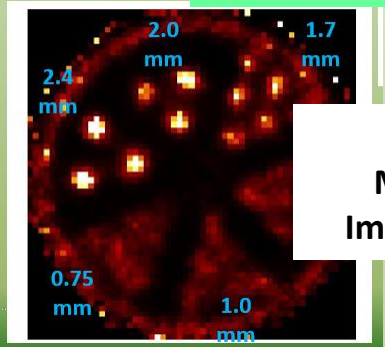


Nuclear Materials Management + D&D

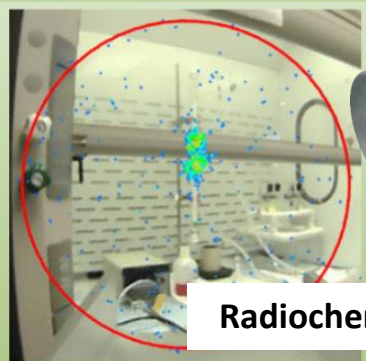


Research

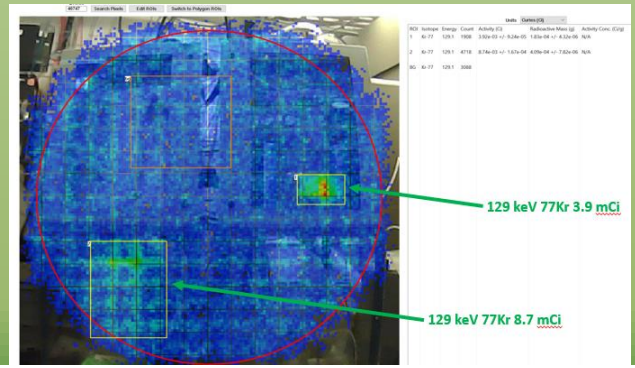
Ray Detectors



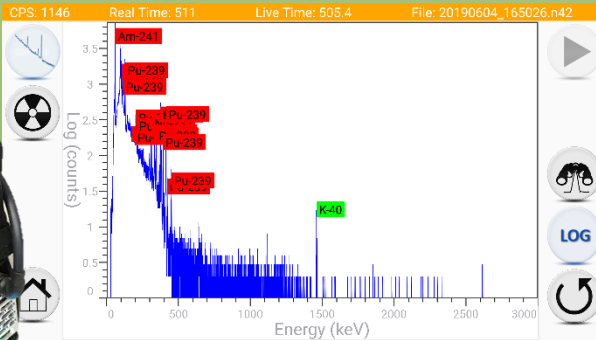
Nuclear Medicine Imaging R&D



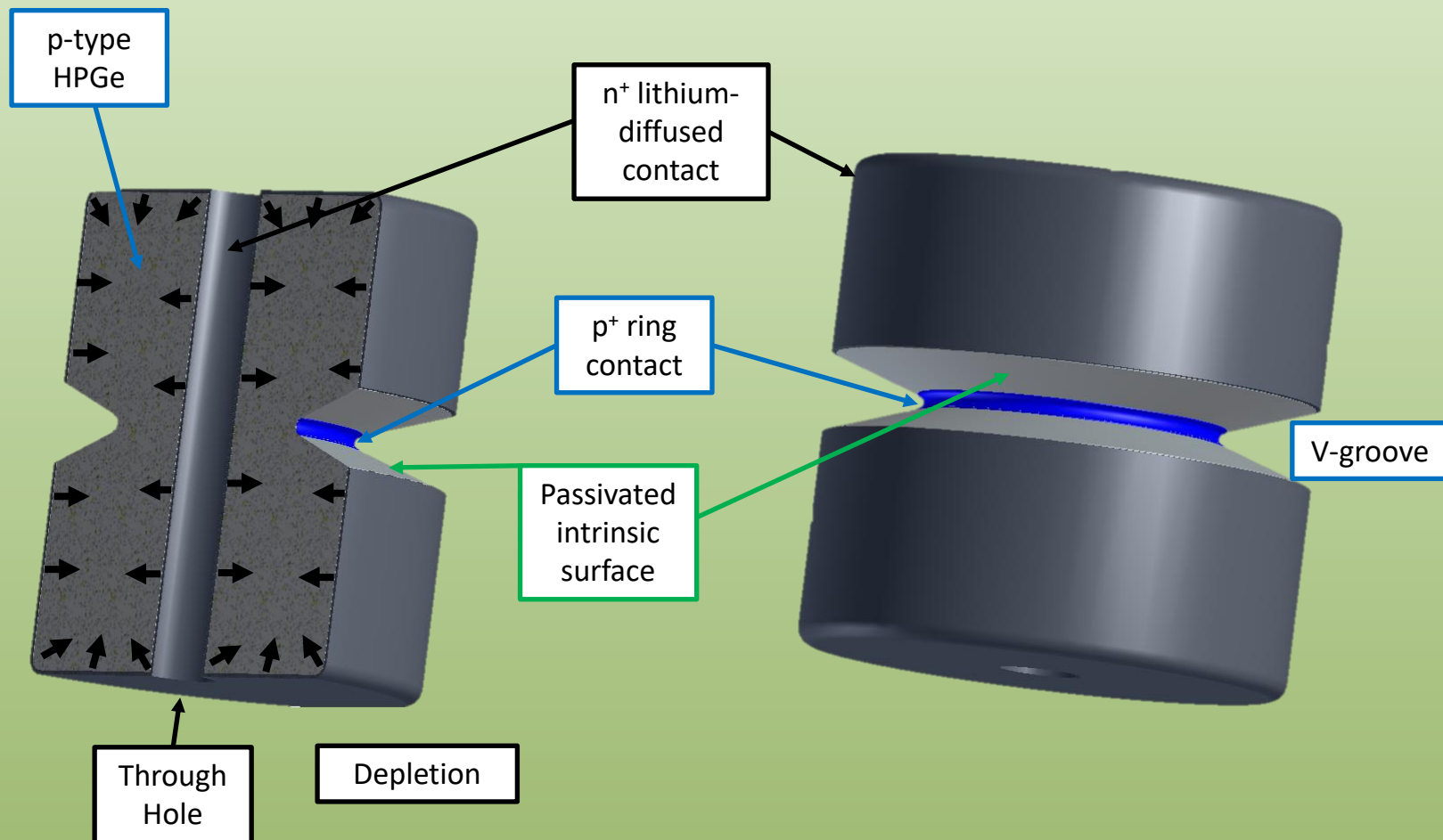
Radiochemistry



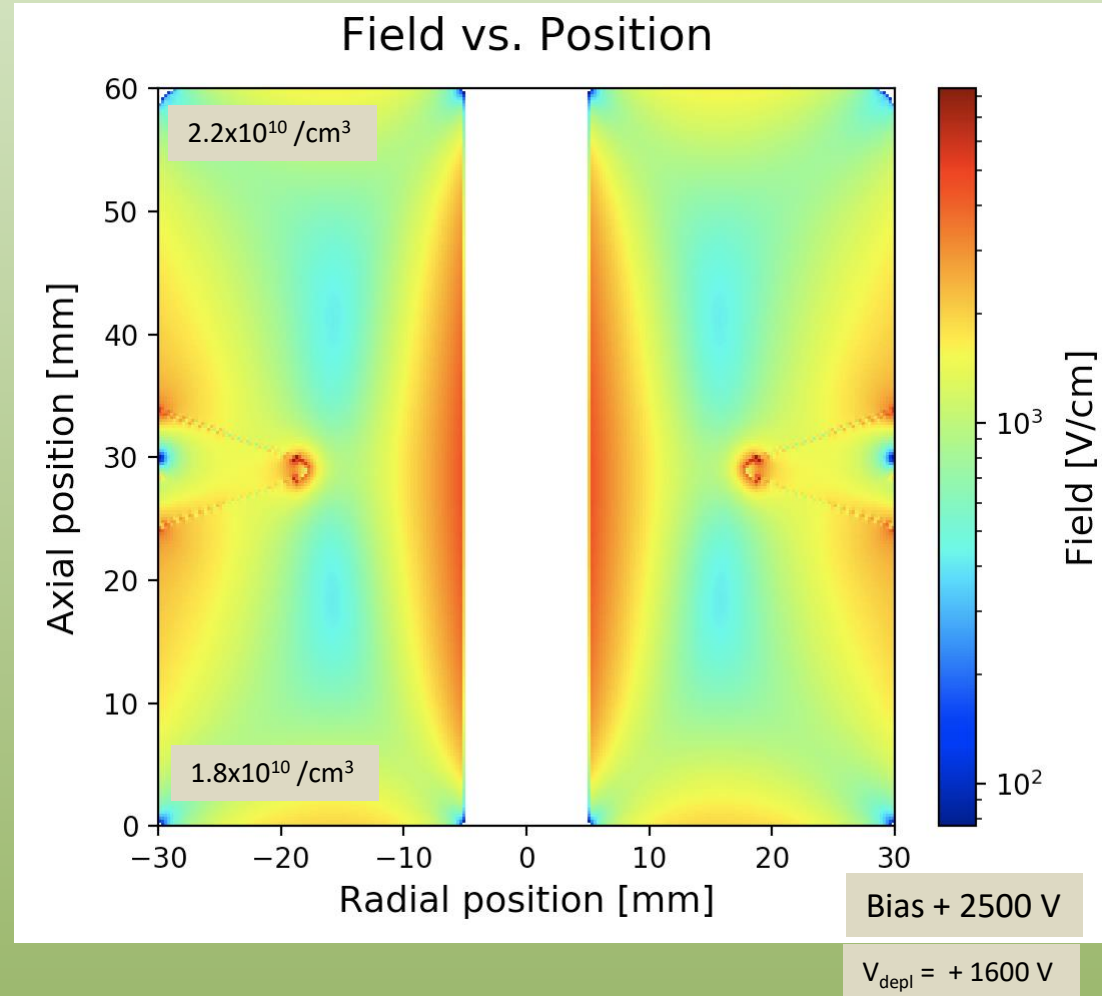
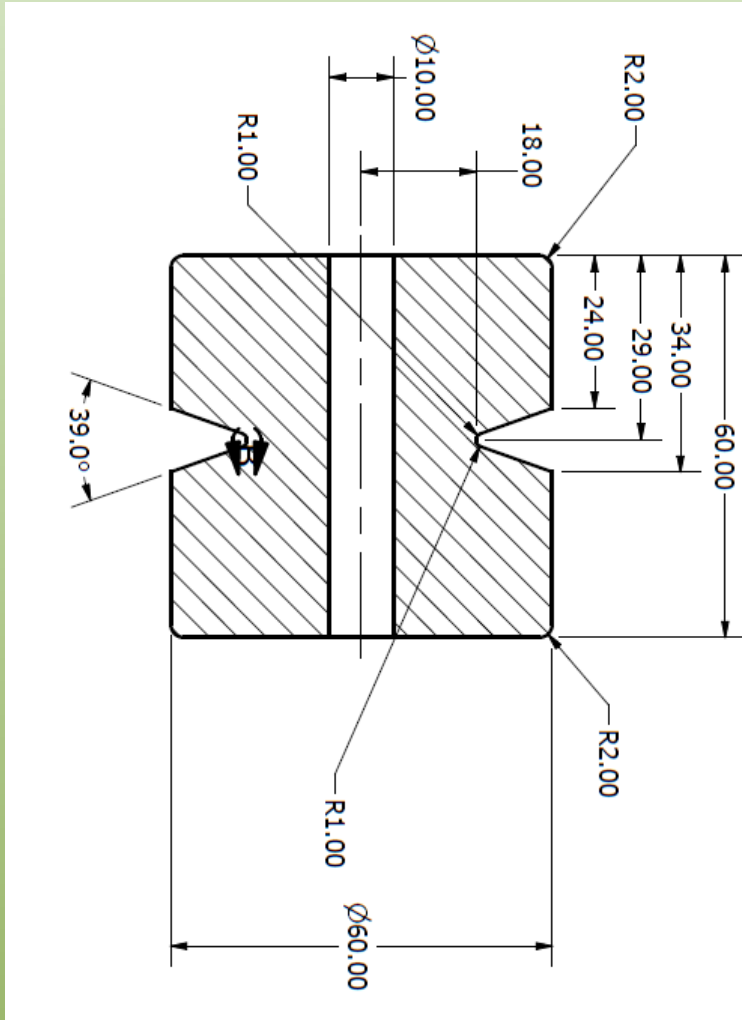
R&D Isotope production / harvesting



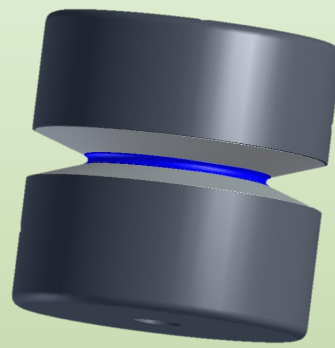
Ring Contact Detector (RCD) Concept – David Radford



Ring Contact Detector (RCD) Concept – David Radford



Electrostatics Calculations show
scalability up to 8 kg of depleted HPGe



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

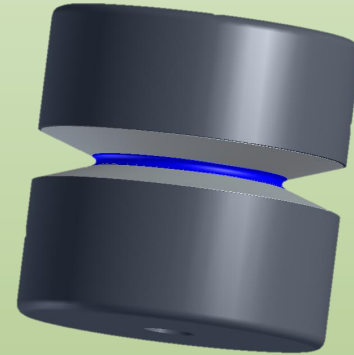
- Diamond Grinding
- Polishing
- V-Groove
- Through Hole

2. Semiconductor Detector Processing

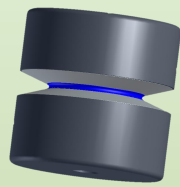
- Etch
- Lithiation
- Boron Implanatation
- Intrinsic Surface Passivation
- Testing

3. Crystal Growth

- Uniformity
- Length of HPGe Region
- Charge Collection



1. Mechanical Preparation

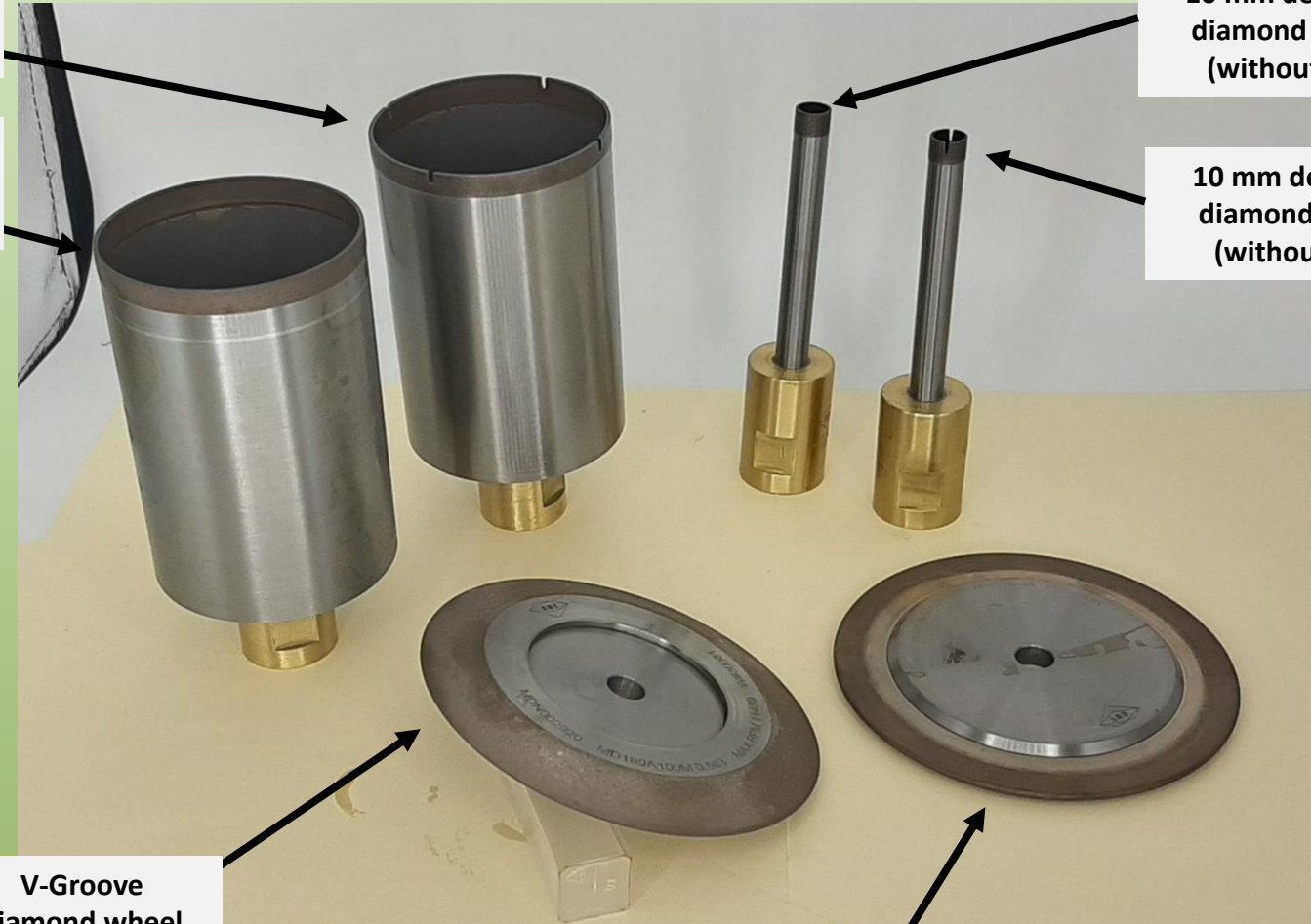


60 mm deep-form diamond core bit (with slots)

60 mm deep-form diamond core bit (without slots)

10 mm deep-form diamond core bit (without slots)

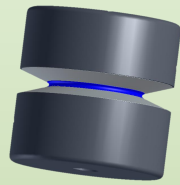
10 mm deep-form diamond core bit (without slots)



V-Groove diamond wheel

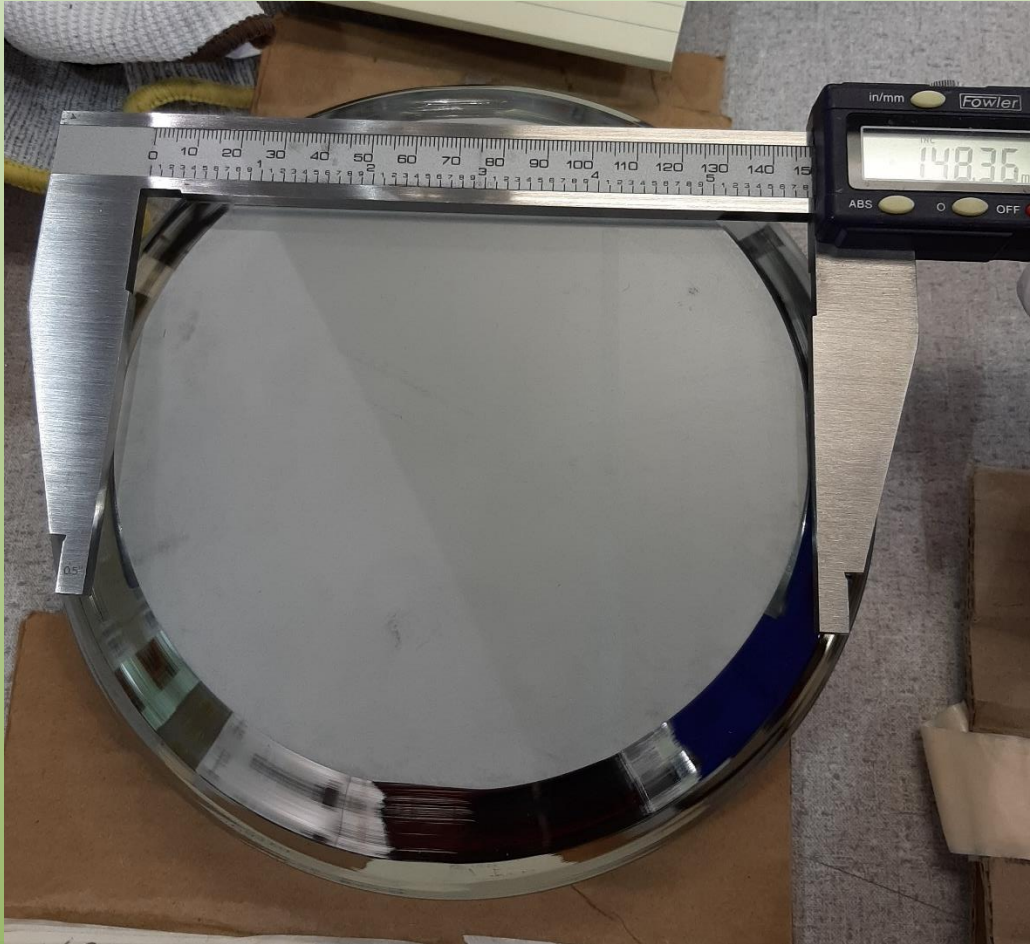
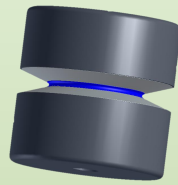
Flat diamond wheel

1. Mechanical Preparation Develop technique



Practice slab of non-detector grade HPGe

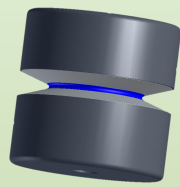
1. Mechanical Preparation



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

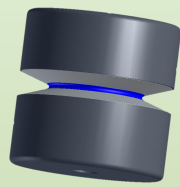
**Prototype RCD detector cut from a slab
of detector-grade HPGe**

1. Mechanical Preparation



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

1. Mechanical Preparation

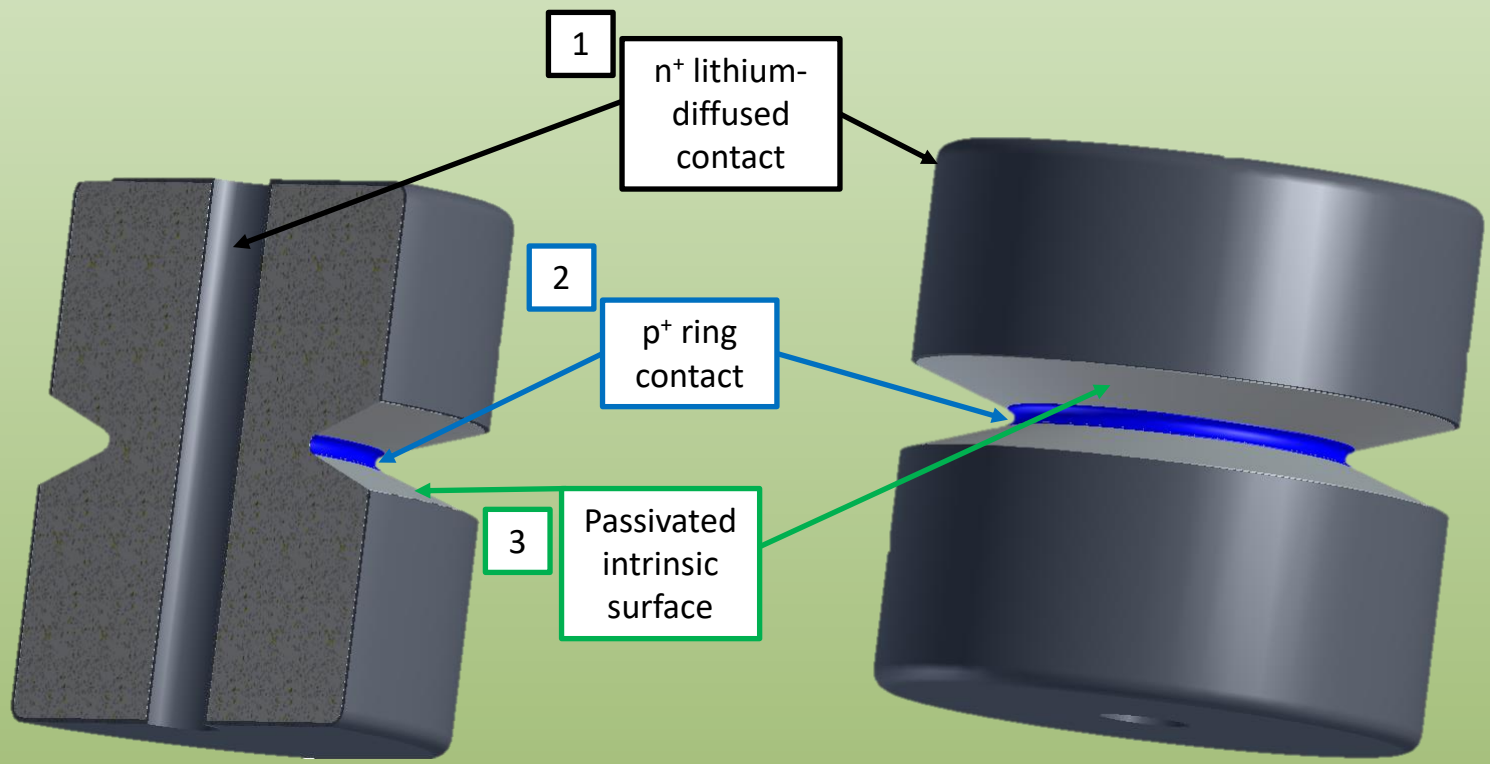
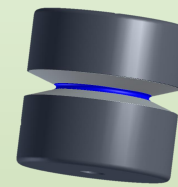


10 mm hole bore



and polish - ready

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



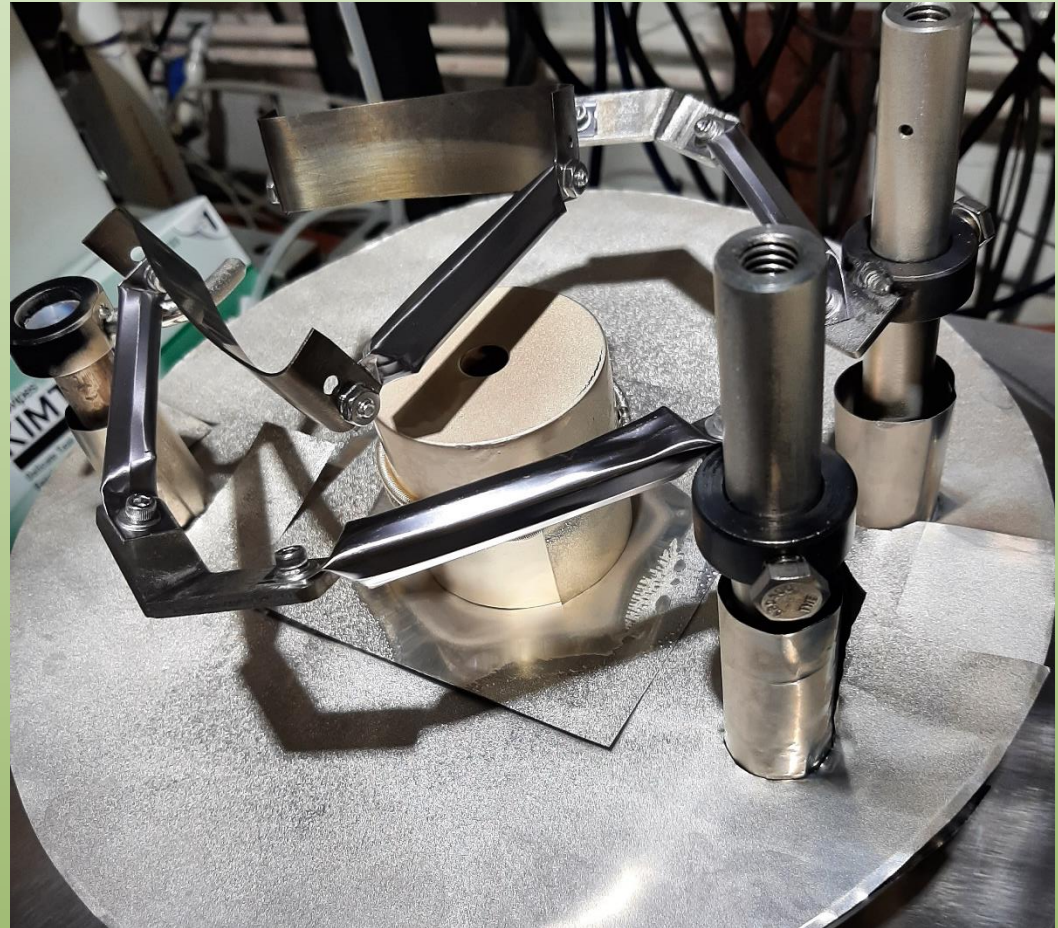
2. Semiconductor Detector Processing Chemical Etch



2. Semiconductor Detector Processing Lithium



Li thermal diffusion system

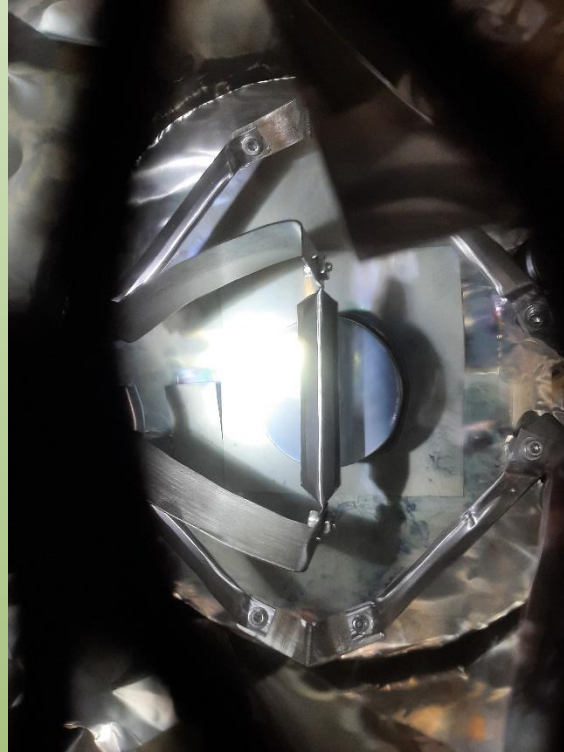


**Special 5-boat array to accommodate through hole
Evaporate Li, then heat to 170C for 2 hours in vacuum**

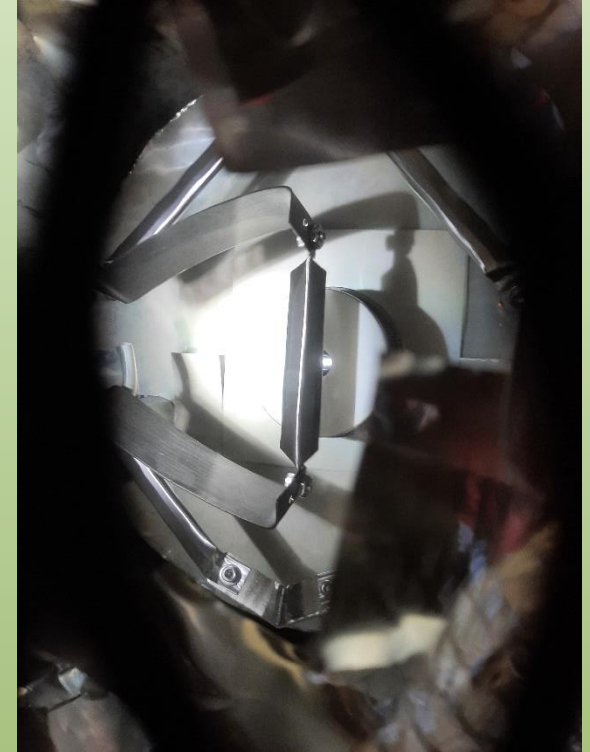
2. Semiconductor Detector Processing Lithium evaporation and diffusion



0 minutes

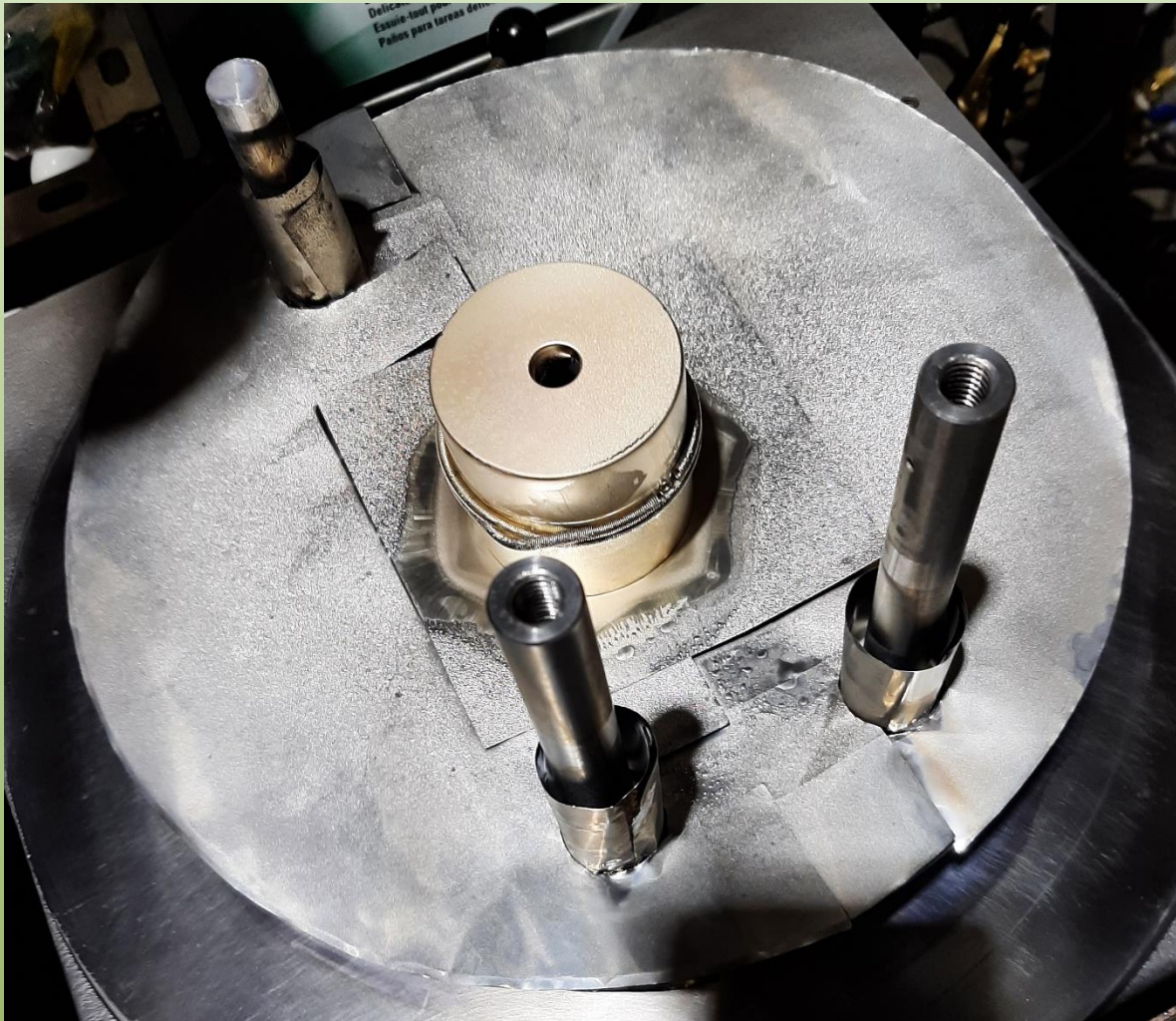


1.5 minutes



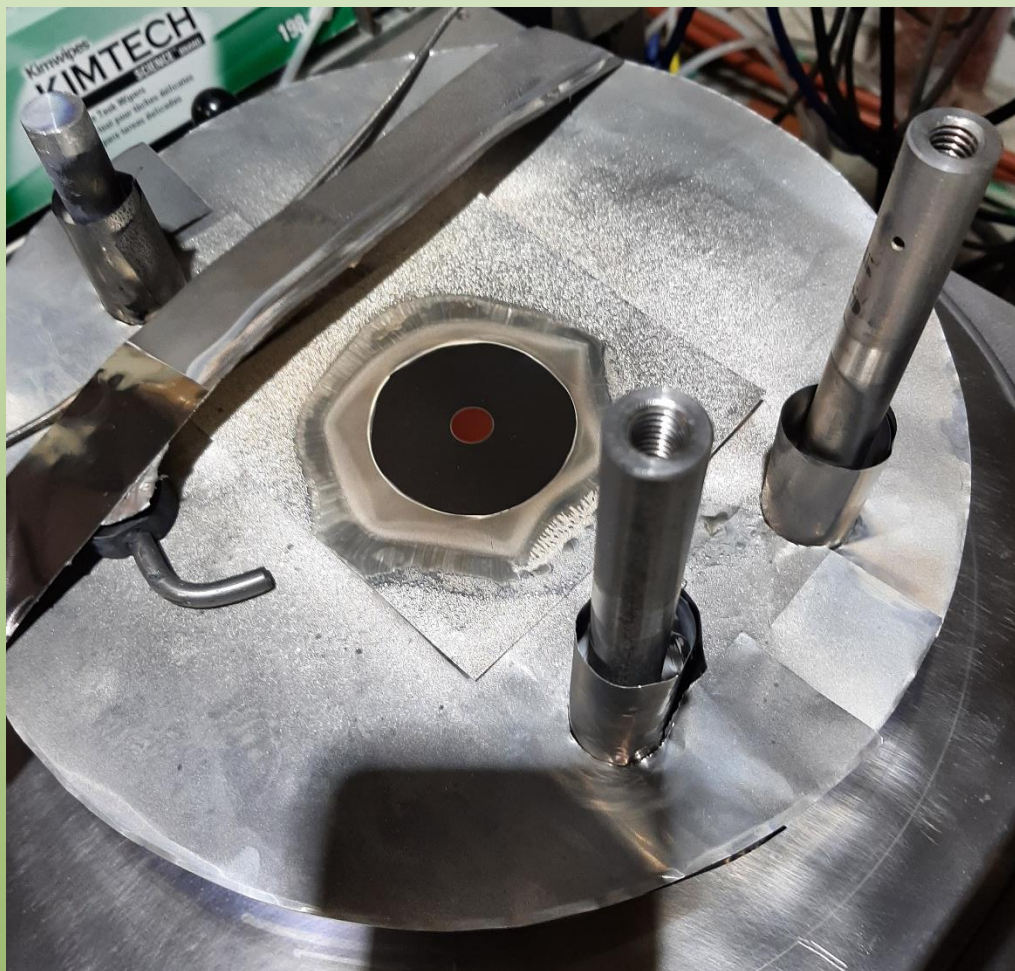
3.0 minutes

2. Semiconductor Detector Processing Lithium evaporation and diffusion



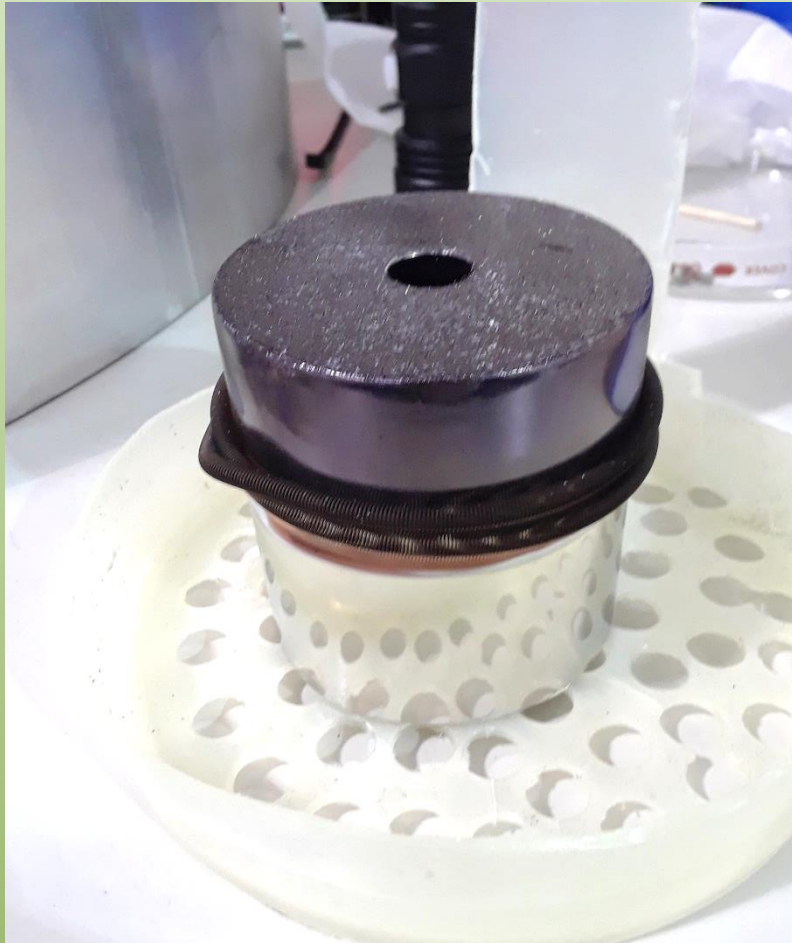
Lithium
coating

2. Semiconductor Detector Processing Lithium

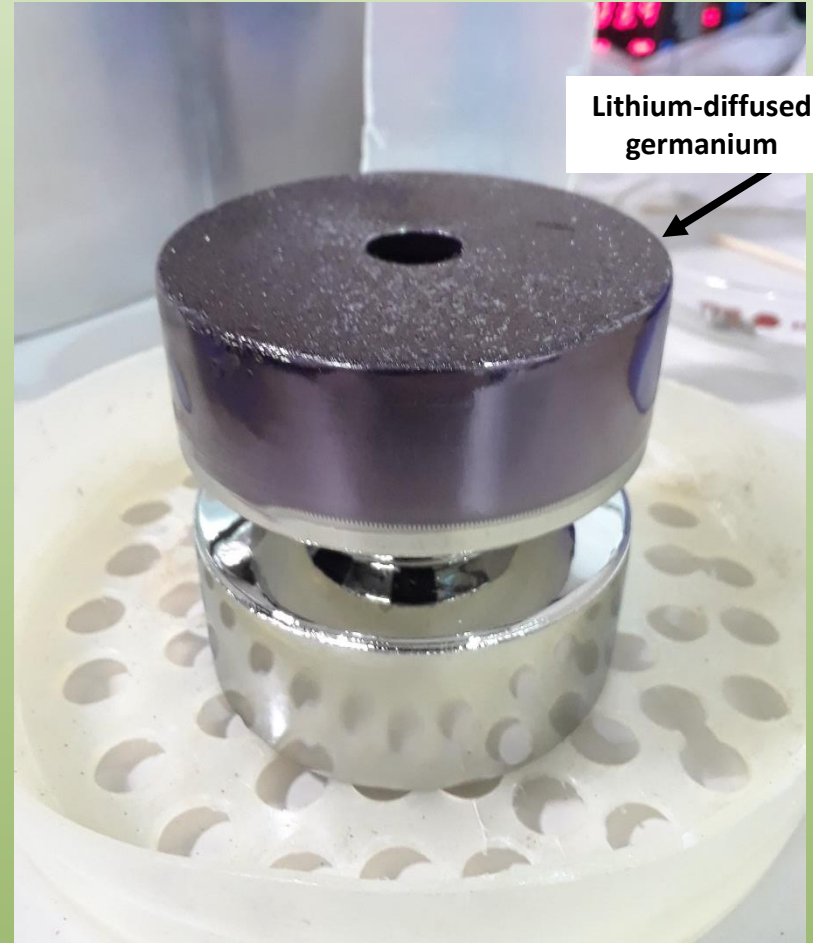


5th boat spot on ss foil through the hole

2. Semiconductor Detector Processing Lithium

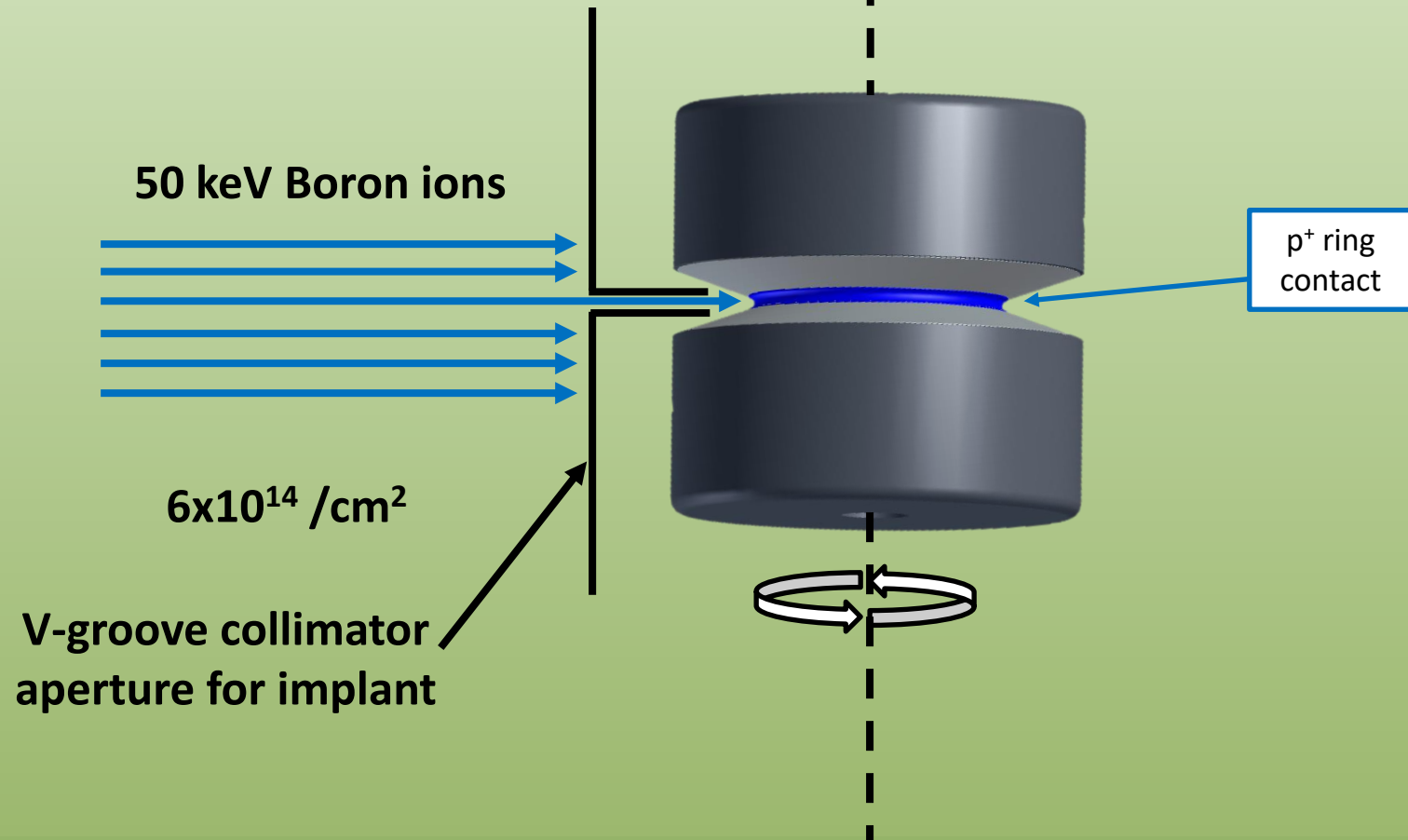


ss foil shield with coil spring

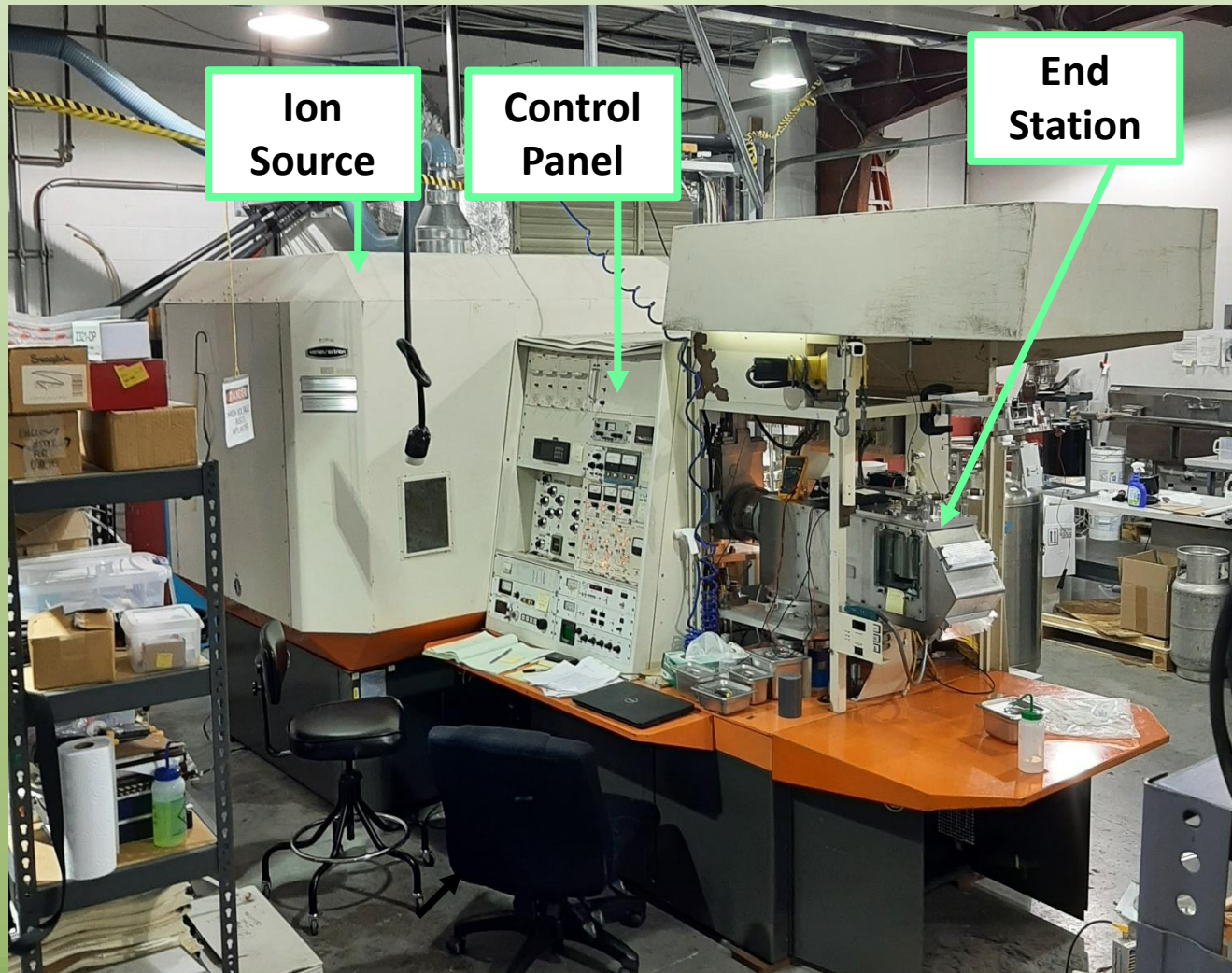


Repeat lithium diffusion with
the detector inverted

2. Semiconductor Detector Processing Boron Implant

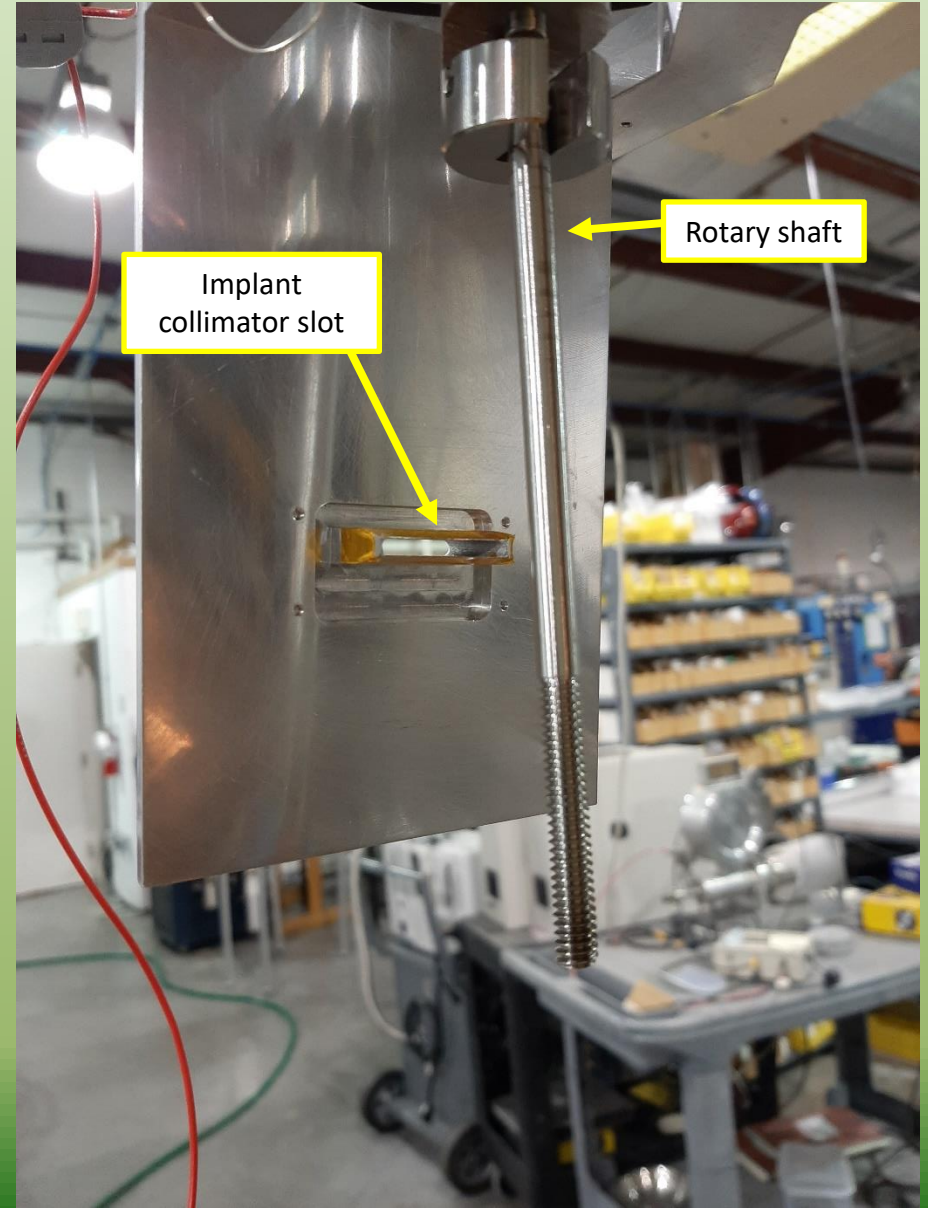
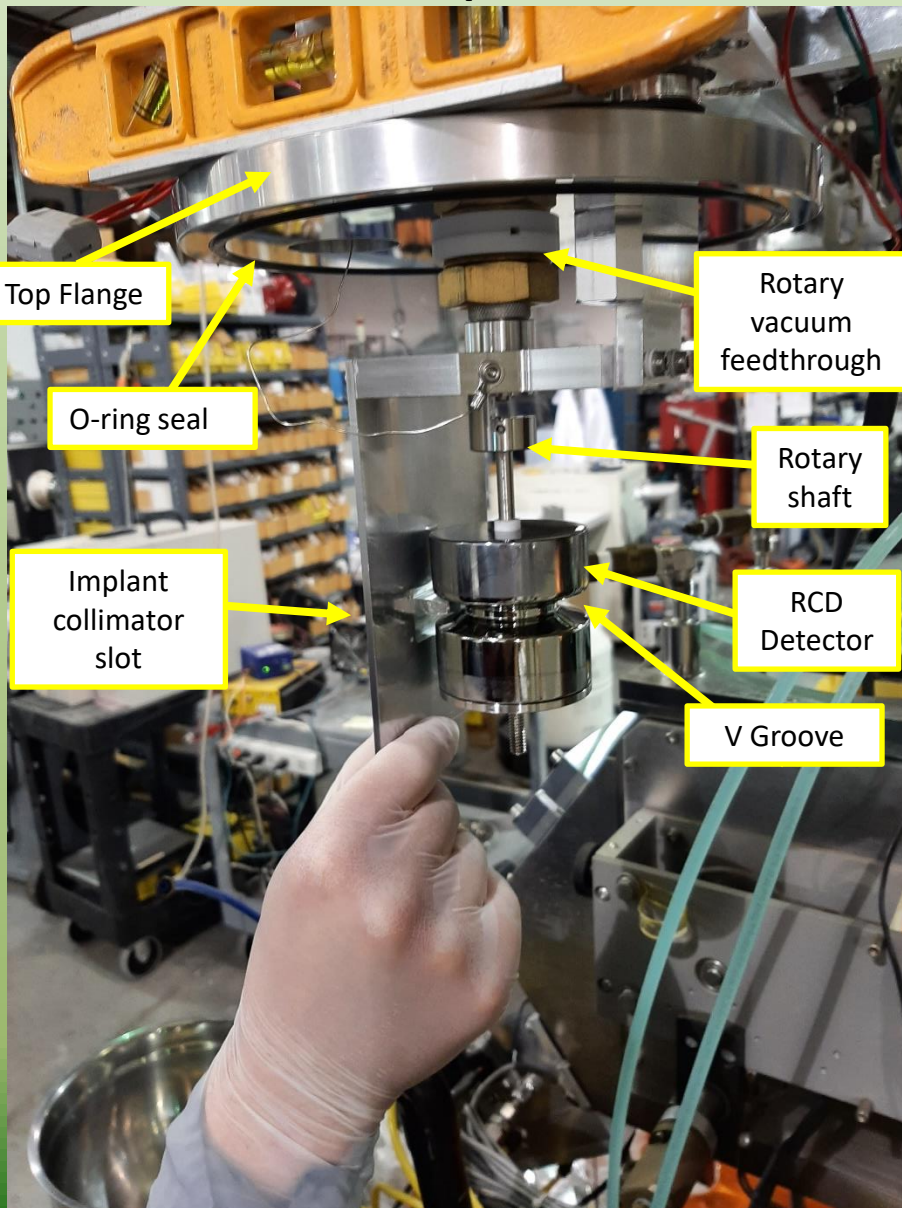


2. Semiconductor Detector Processing Boron Implant – Ion implantation system



The end station required modification to fabricate the RCD

2. Semiconductor Detector Processing Boron Implant – RCD End Station

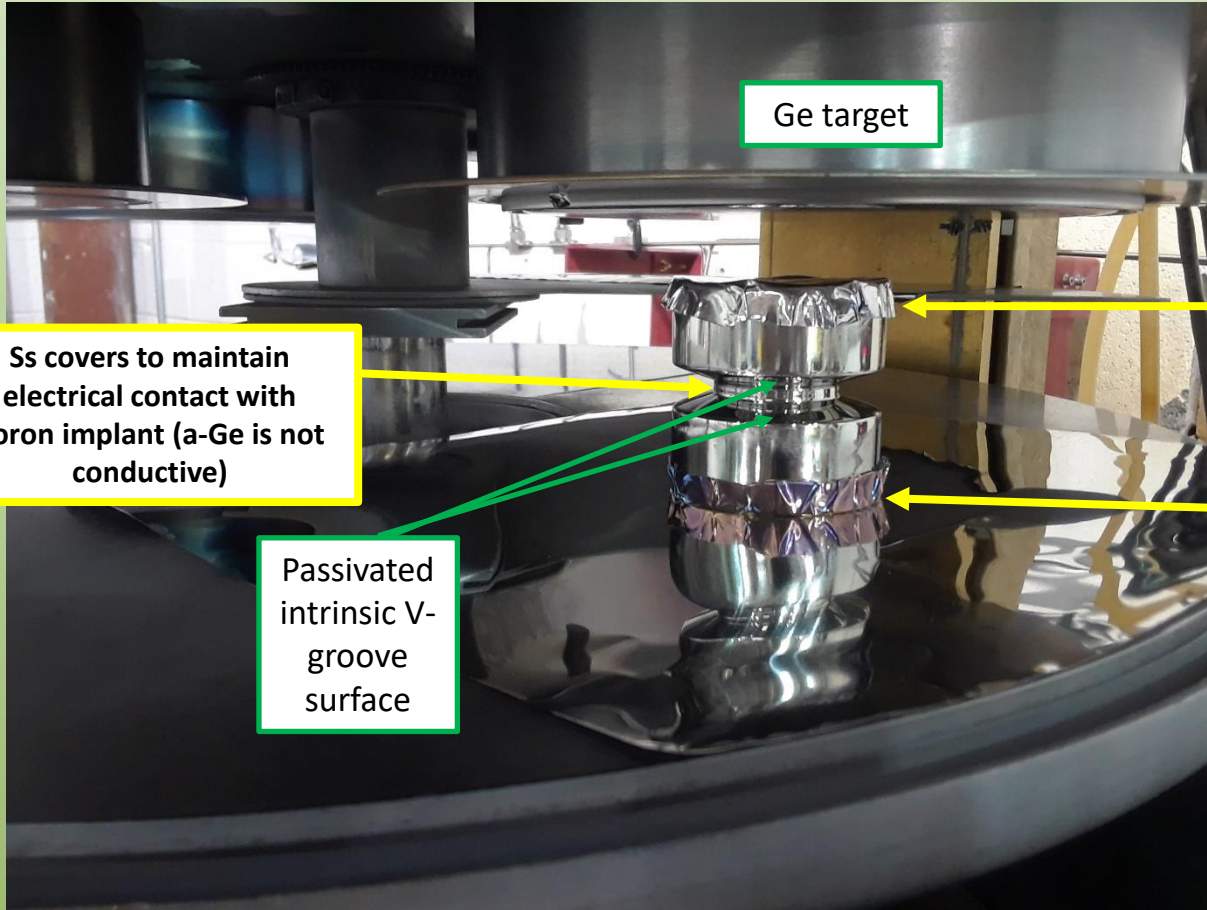


2. Semiconductor Detector Processing Boron Implant – Rotating detector mount



2. Semiconductor Detector Processing

Passivation – amorphous germanium (V-groove)



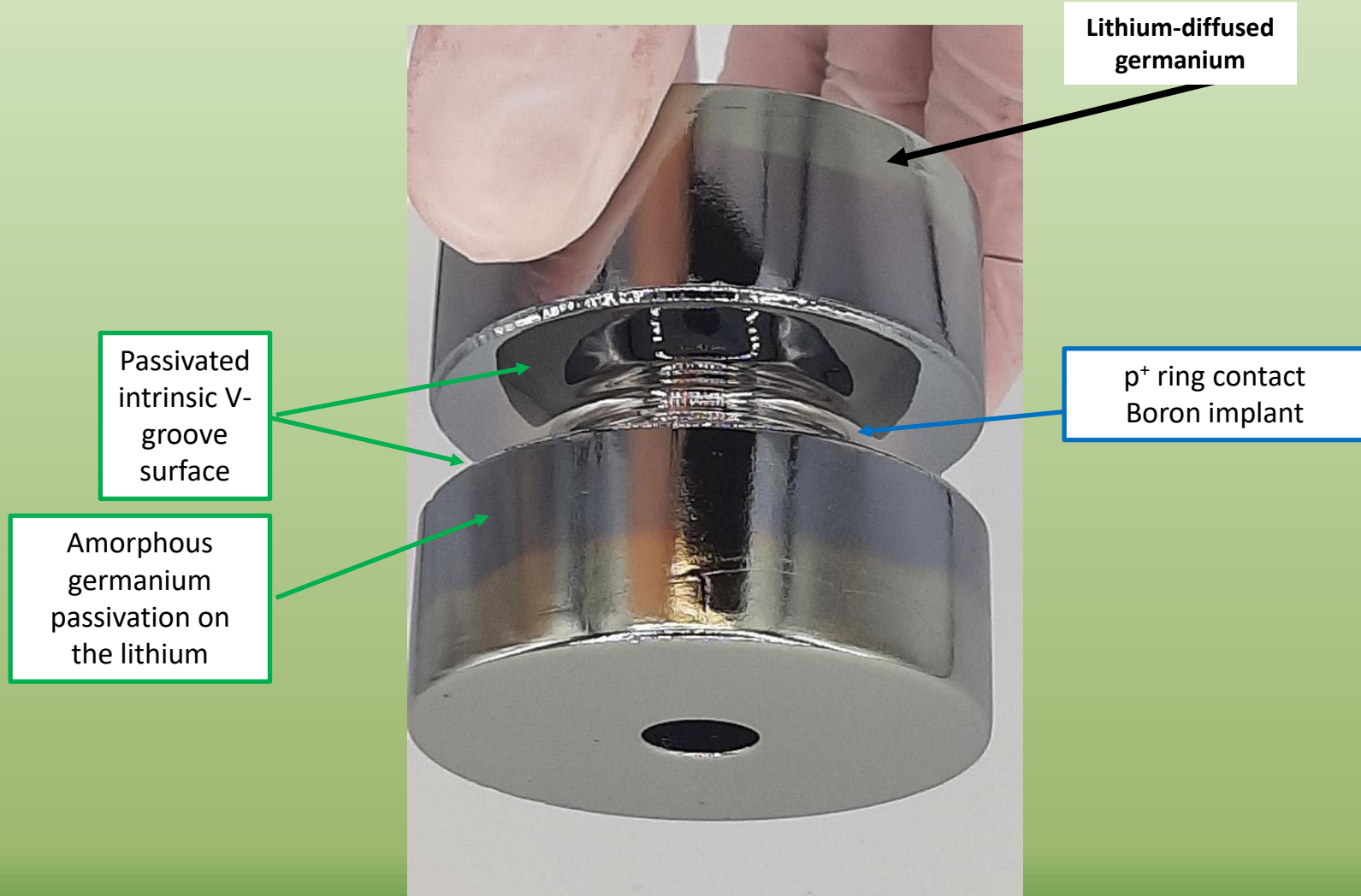
Ge target

Ss covers to maintain electrical contact with Li (a-Ge is not conductive)

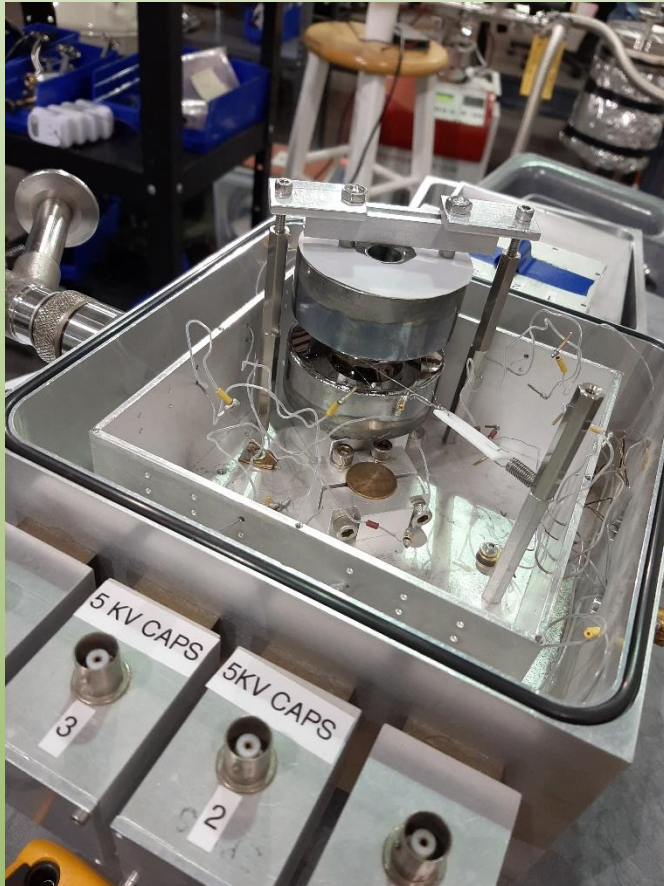
Ss covers to maintain electrical contact with boron implant (a-Ge is not conductive)

Passivated intrinsic V-groove surface

2. Semiconductor Detector Processing Finished detector



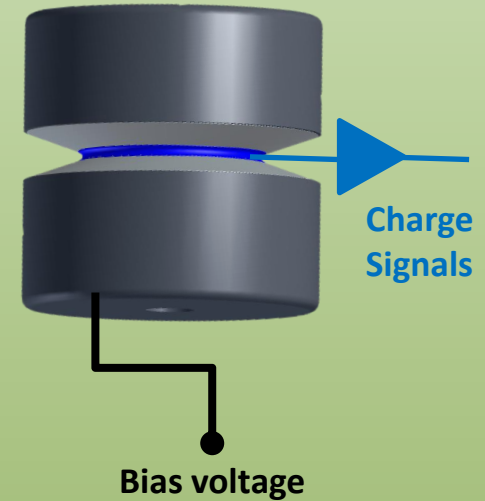
2. Semiconductor Detector Processing Finished detector - testing



Mounted in a four-place test cryostat

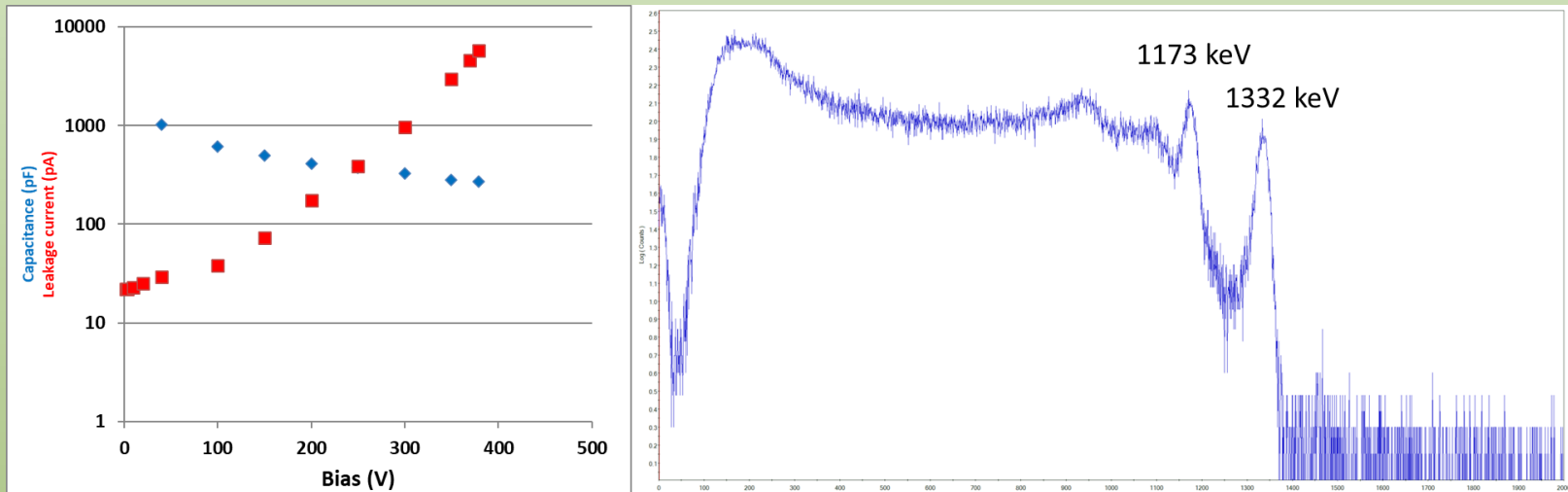


Spring loaded wire loop on ring contact.
This is the signal contact



2. Semiconductor Detector Processing

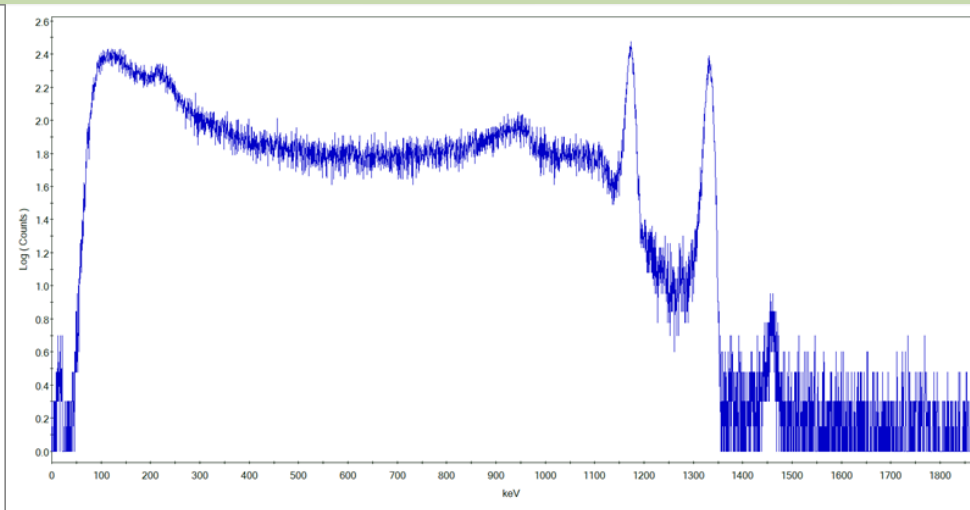
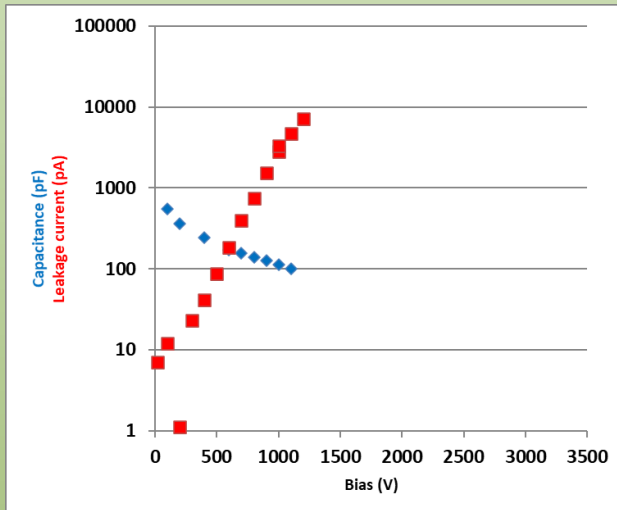
RCD detector testing



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

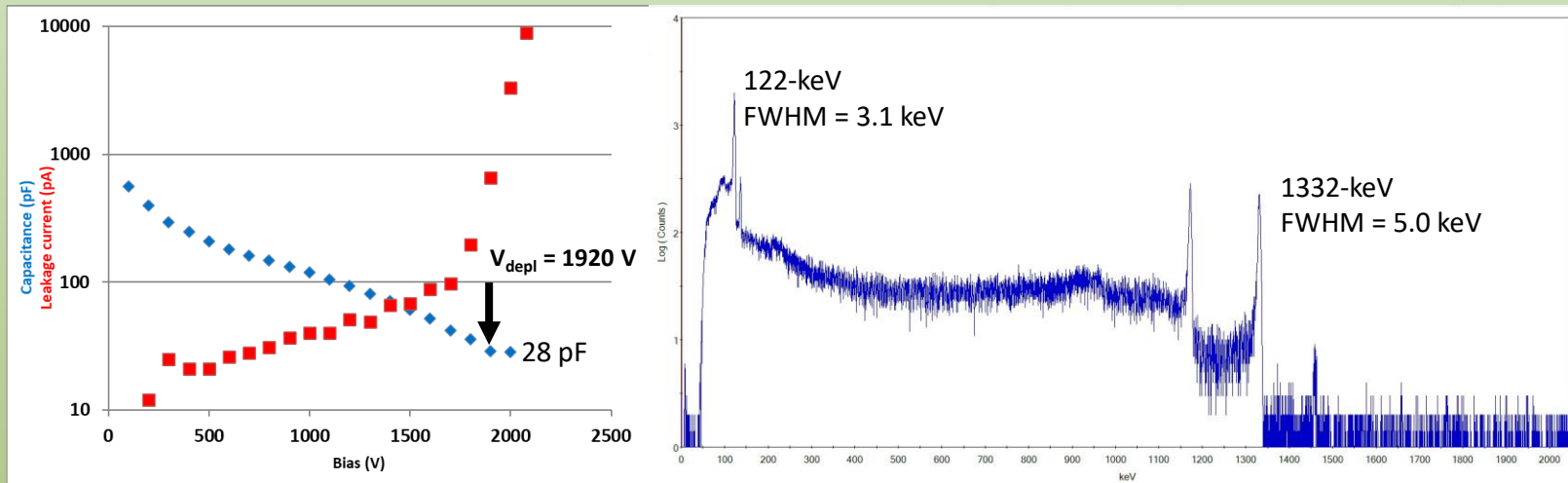
2. Semiconductor Detector Processing RCD detector testing

-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.

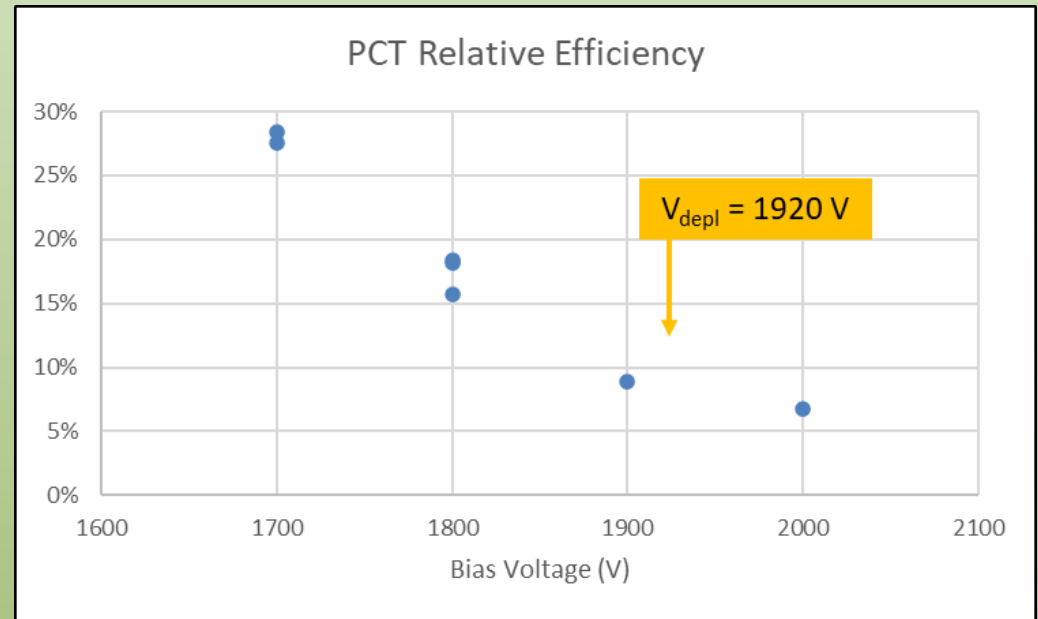
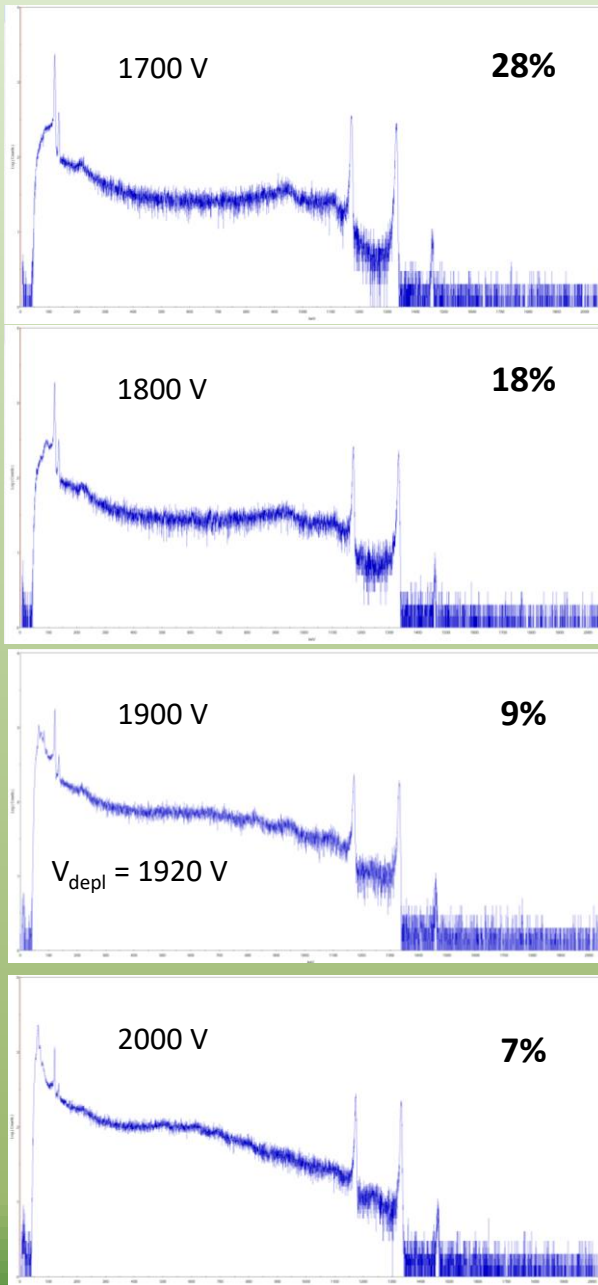


A more recent test shows the detector taking 2200 V.
A spectrum was measured at 1800 V. $V_{\text{depl}} = 1920 \text{ V}$.

Progress points

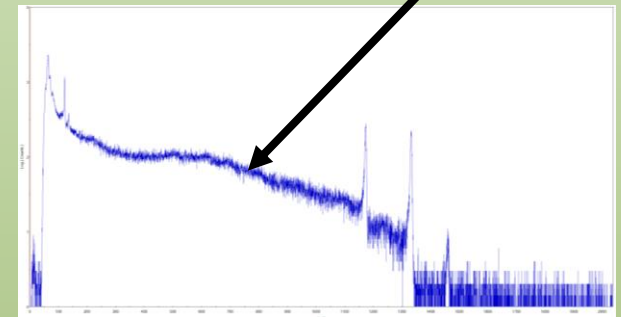
- Depleted Detector – 1920 V is reasonable
- Capacitance is reasonable
- Spectroscopy is so – so
 - Working on this now...

Semiconductor physics observation



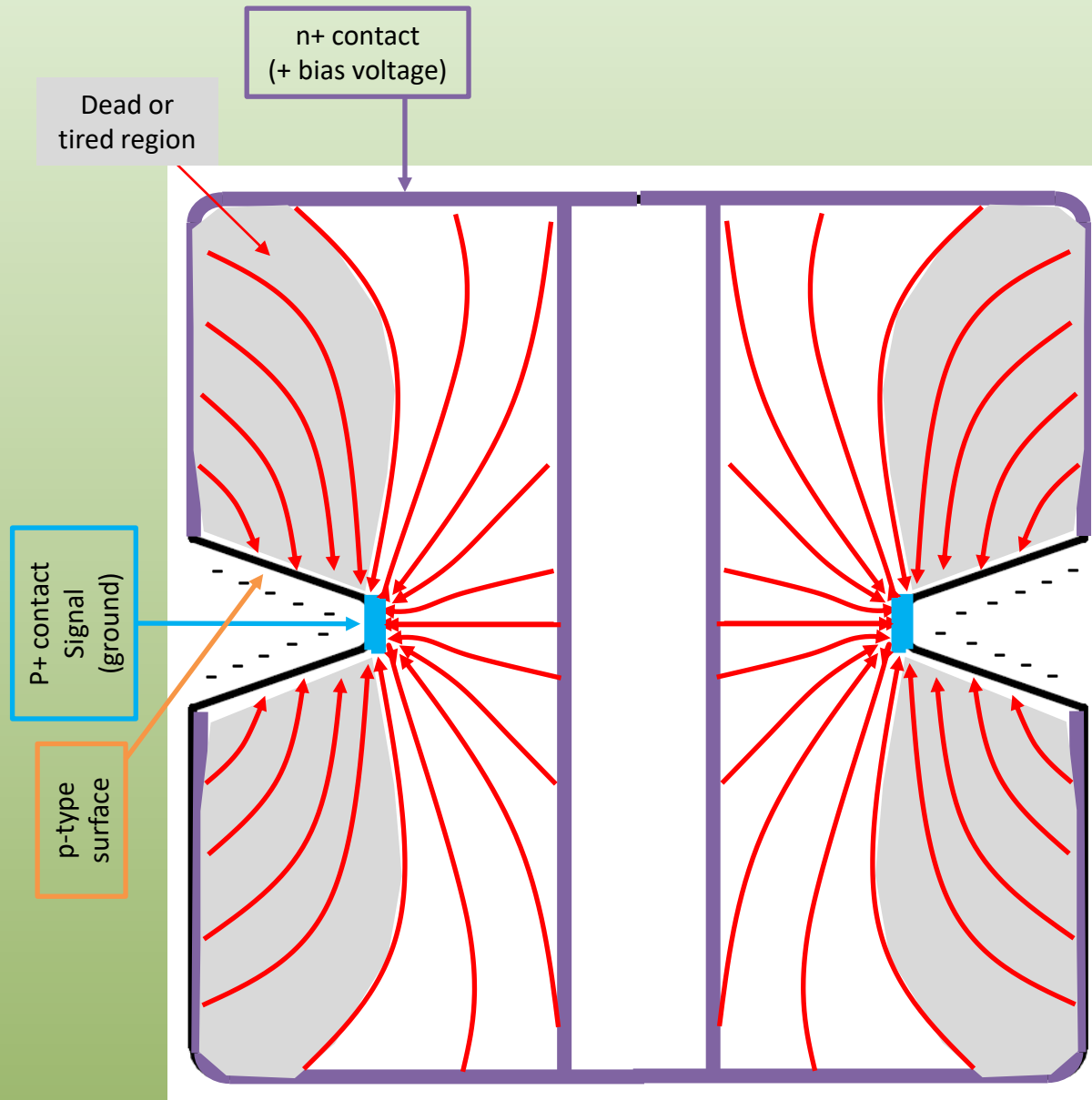
The full-energy 1332-keV peak efficiency decreases dramatically with increasing bias near V_{depl} – an interesting result

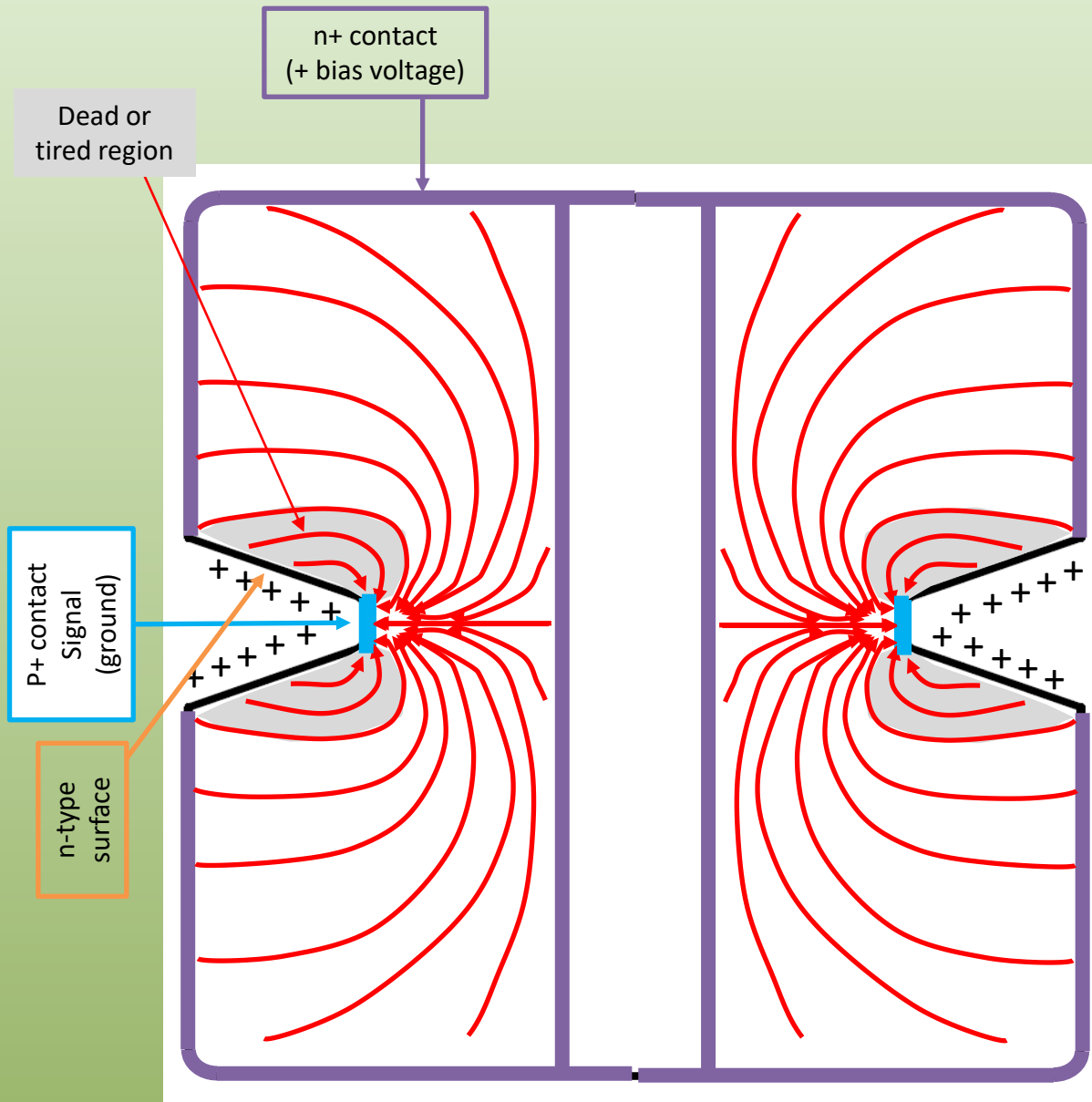
Any holes reaching the p-type intrinsic surface are effectively stopped and contribute little (if any signal)



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

p-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)

n-type surface channel

RCD Phase II

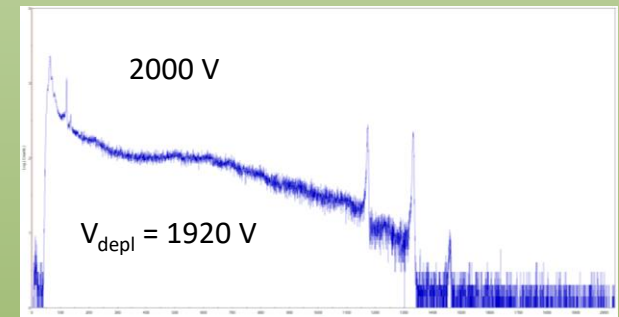
1. Mechanical Preparation



2. Semiconductor Detector Processing



3. Crystal Growth



Thank you