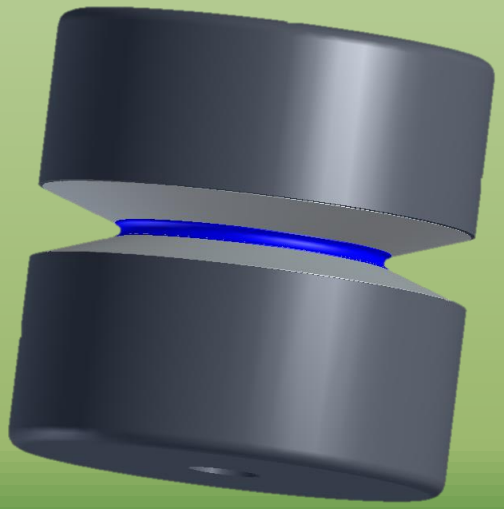
PHDS
Gamma Ray Detectors

# LARGE VOLUME RING-CONTACT HPGE DETECTORS (RCD)

## NP SBIR Phase II Year 2 No Cost Extension

## 20240814 NP SBIR Exchange Meeting

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



## PHDS Co. Background

- 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
  - Detector Fabrication
  - System Integration
  - Software application
  - Sales & Service

Enabling Capabilities

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**NPX (150 lbs.)**
**2008 Laboratory**

**NP Imager**


**Fulcrum-40h (13 lbs.)**
**2023 Hand Portable Spectrometer**


Specialty Operations Products

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**

**LoPro (8-11 lbs.)**
**2020 Specialty Spectrometer**

***All PHDS Co. HPGe detector systems are mechanically cooled.***

## *Frontiers* of Nuclear Physics

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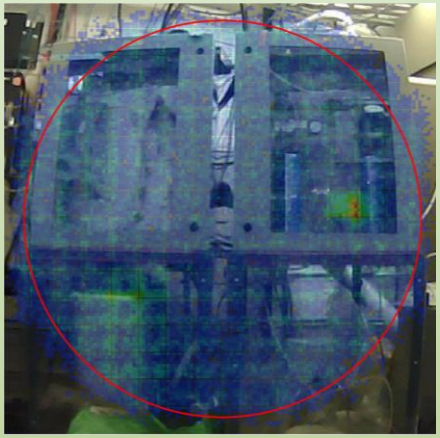



## *Front lines* of Nuclear Security


## *Front row* of NDA

## *Front Page* of Isotope Production

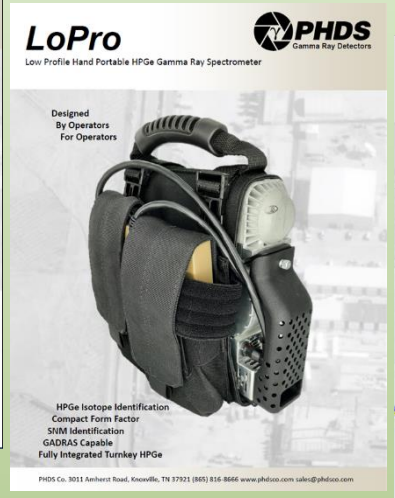
# PHDS Co. now manufactures and sells 5 HPGe products

PHDS

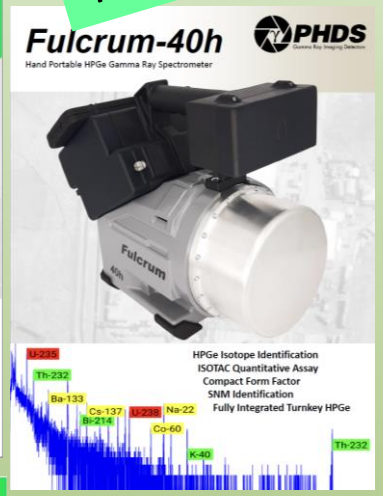
Gamma Ray D

New Fall 2022











**Detect, Identify, Locate, Quantify**

**Imager**


**Identify, Quantify, Fast Cool down**


**Detect, Identify Special Apps**


**Radiochemistry, Rare Isotopes**

**Imager**


**Identify, Quantify, High Sensitivity**

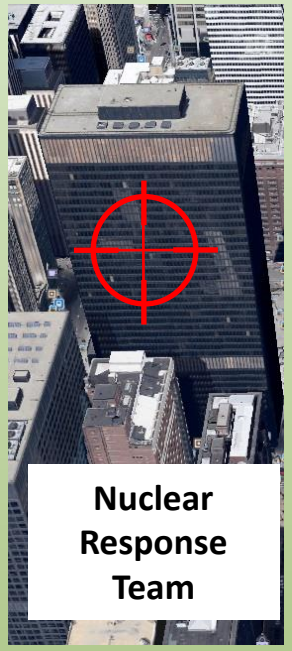
**RCD !!**

# Applications Served by these Products

PHDS Ray Detectors

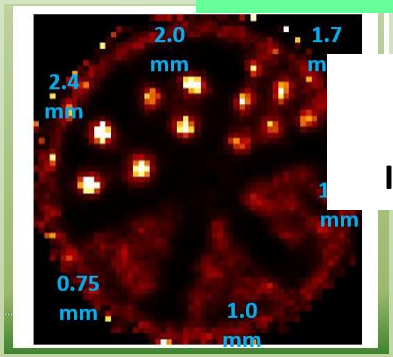
**Nuclear Security 65-75 %**

**Research 25-35%**



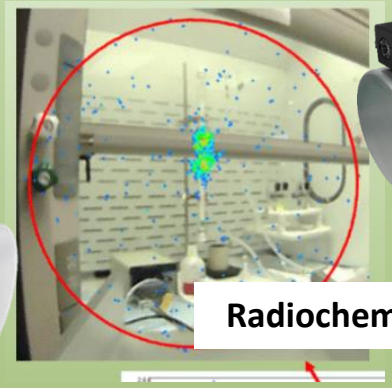
**Nuclear Response Team**



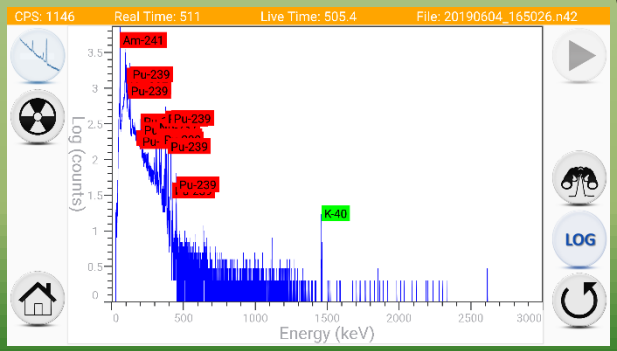


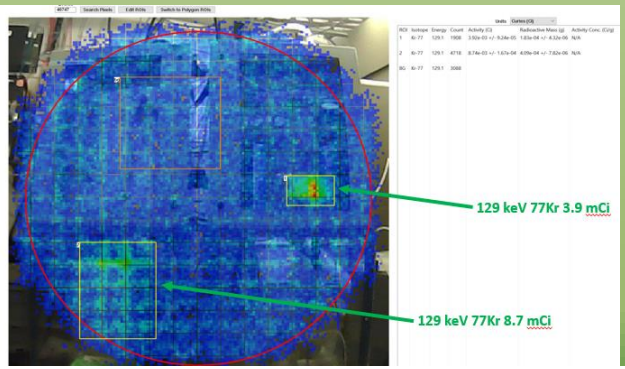

**Radiochemistry, Imaging R&D and Isotope Production**


**Nuclear Materials Management + D&D**


**Radiochemistry**

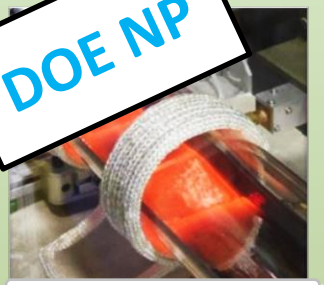




**R&D Isotope production / harvesting**

# PHDS Co. vertical manufacturing

PHDS Gamma-ray Detectors



DOE NP

Ge Zone Refine

DOE NP

HPGe Crystal Growth

DOE NP

Analysis

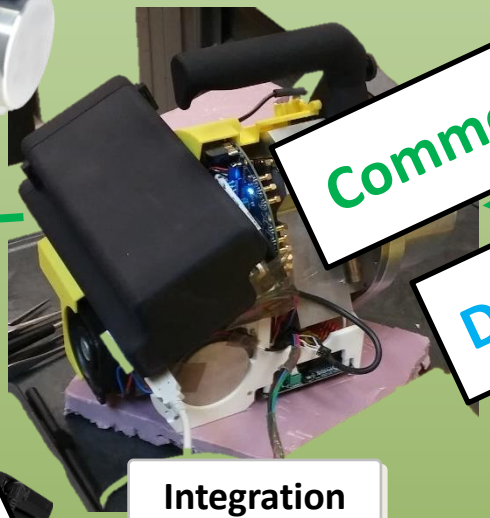
DOE NP

Commercial

Fabrication

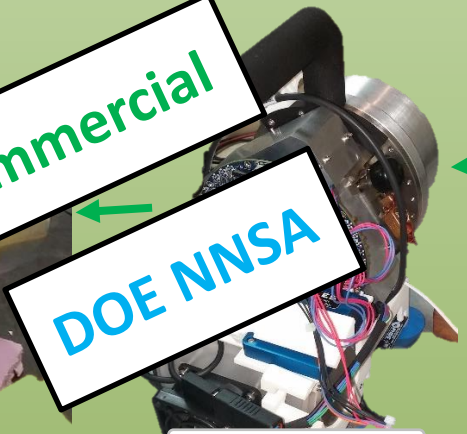
Commercial Products

DOE NP



Commercial

Integration



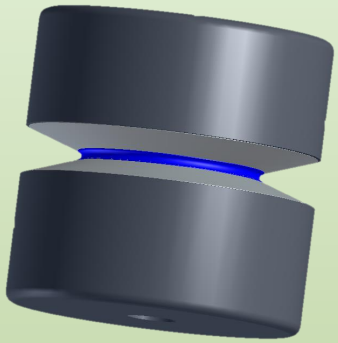
DOE NNSA

Electronics

Commercial

Cryogenics

## DOE NP Grants, Sales and Product Performance



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# Ring Contact Detector
# RCD Features

**Largest Mass**

Fewest Detectors per kg of Ge

Lowest background (connections, mounting etc.)

Majorana + LEGEND

**High efficiency** – R&D and Counting Labs

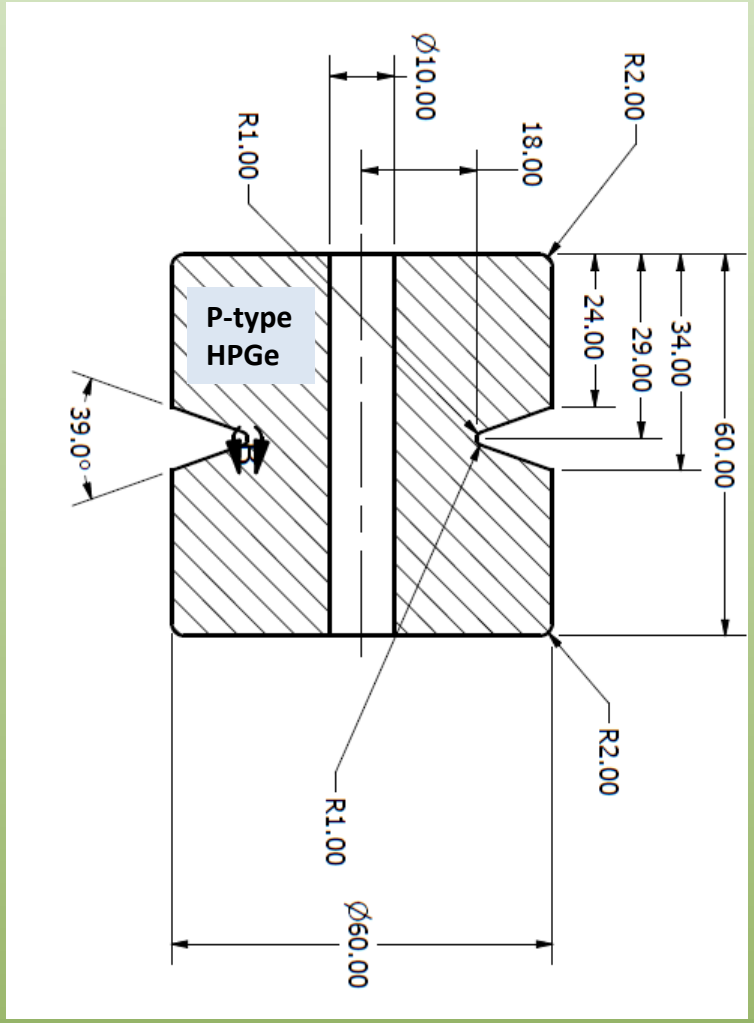
**Counting lab feature:** Hole can be used as a counting well. The hole diameter can be made larger without affecting detector capacitance (noise).

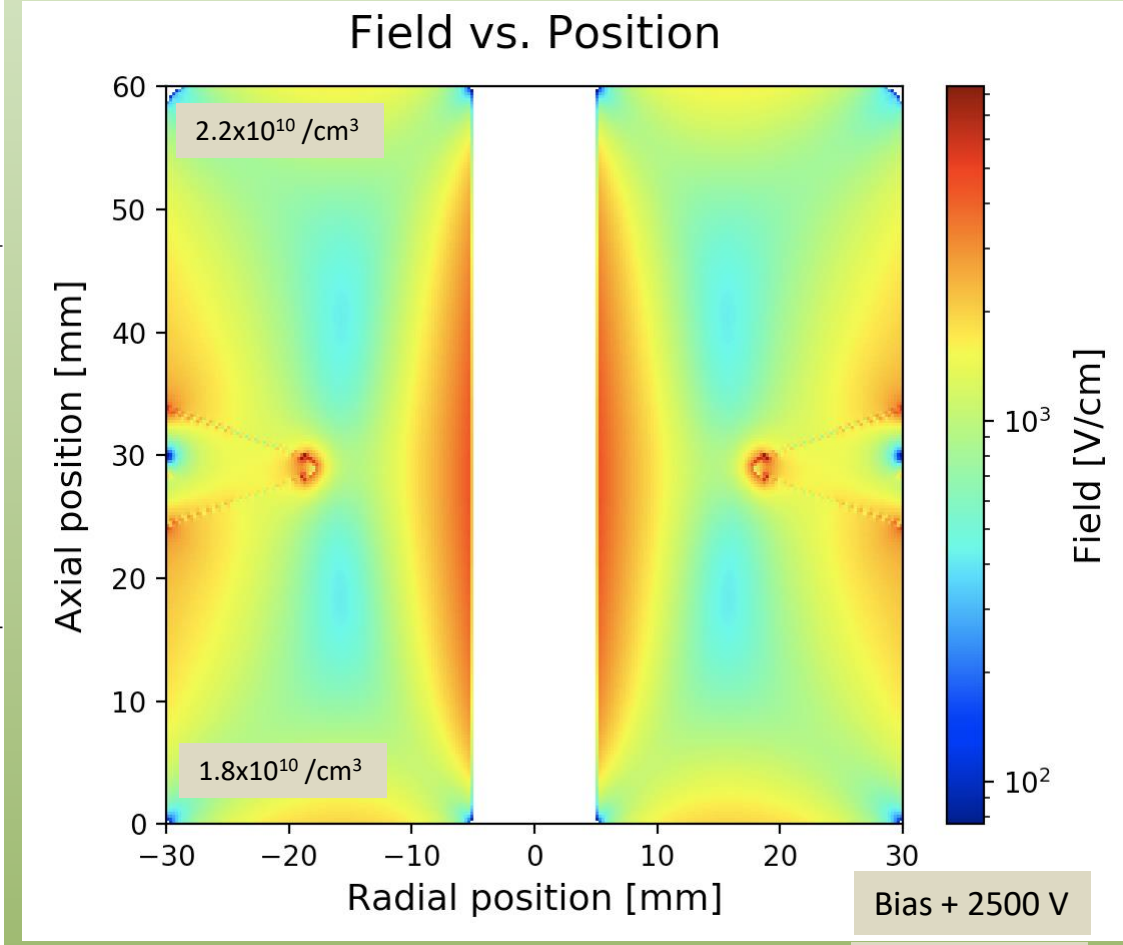
35 mm diameter hole costs only 7-8% of mass

No significant increase in capacitance (noise)

# Ring Contact Detector (RCD) Concept – David Radford

PHDS Gamma Ray Detectors

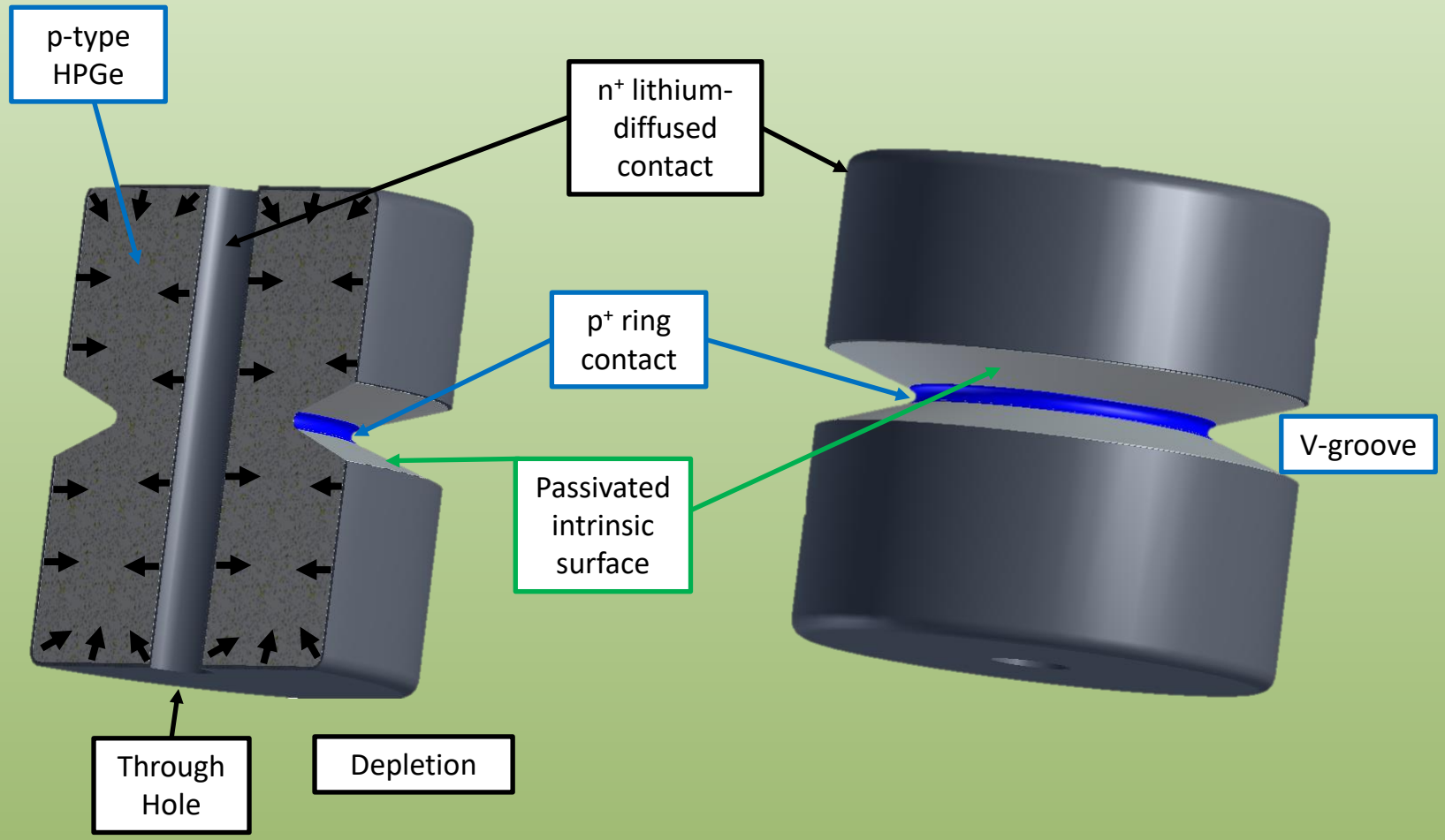



**Electrostatics Calculations show scalability up to <u>8 kg of depleted HPGe</u>**

# Ring Contact Detector (RCD) Concept – David Radford

PHDS
Gamma Ray Detectors



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

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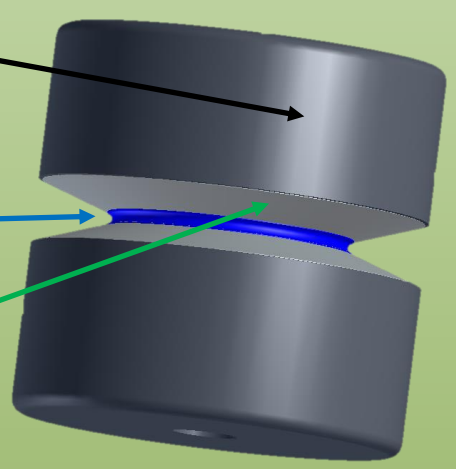
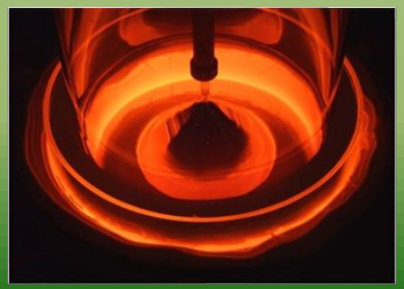
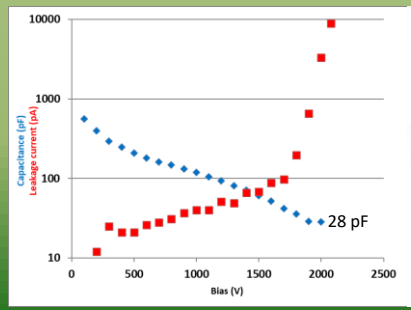
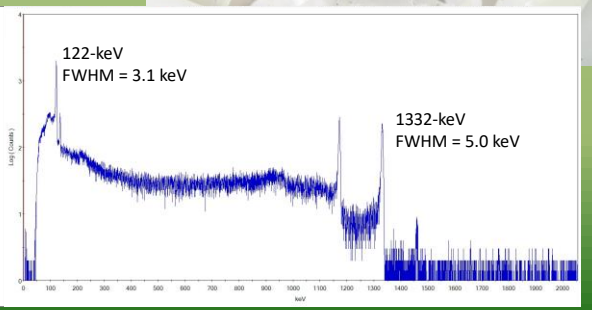
1. **RCD Mechanical Preparation**
   - Diamond Grinding
   - Polishing
   - V-Groove
   - Through Hole
2. **RCD Semiconductor Detector Process**
   - Etch
   - Lithiation
   - Boron Implanation
   - Intrinsic Surface Passivation
   - Testing
3. **RCD Crystal Growth**
   - Uniformity
   - Length of HPGe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

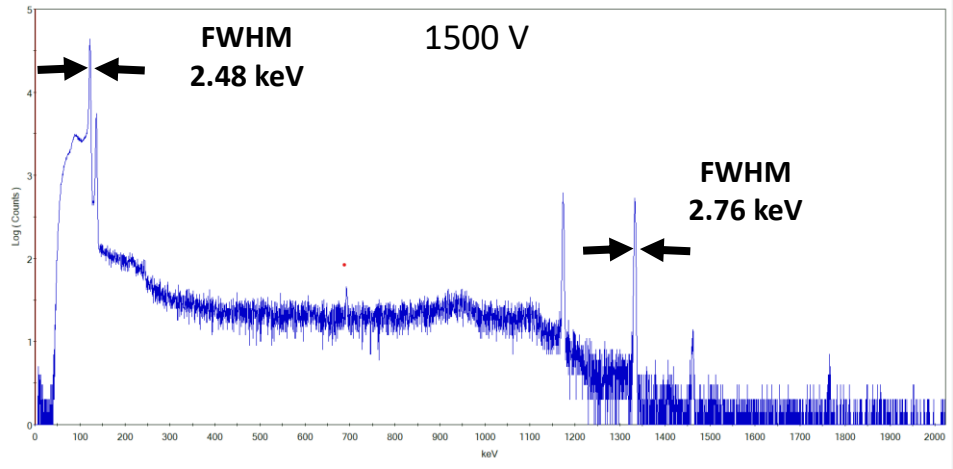


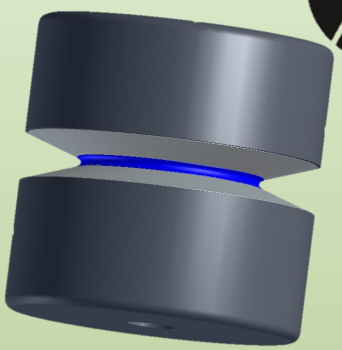


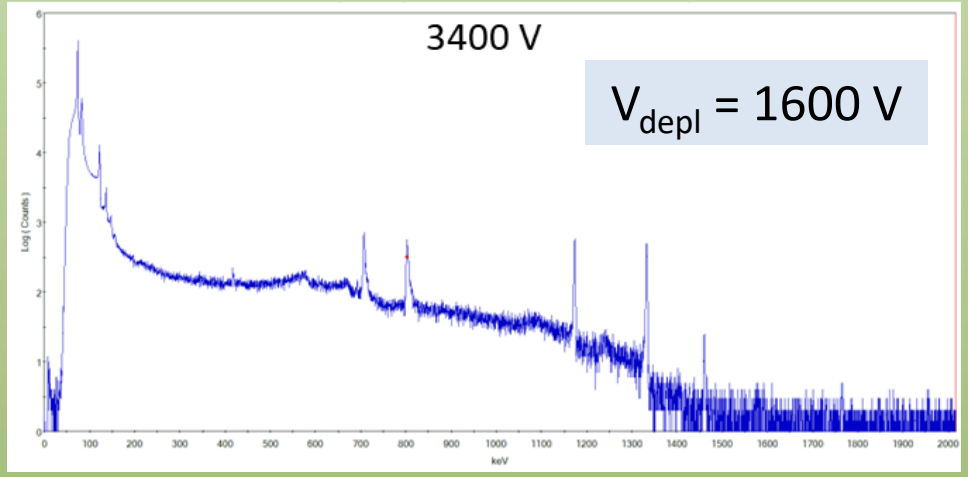



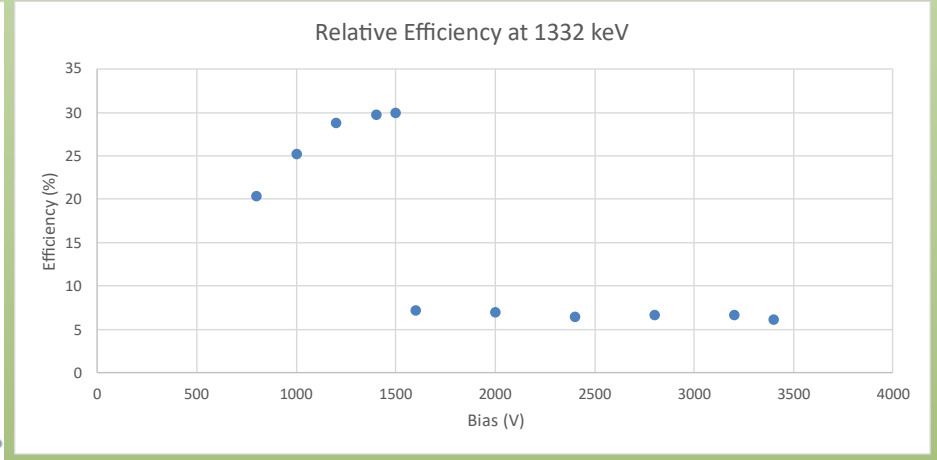
# RCD Detector Results




PHDS
Gamma Ray Detectors






**Significant loss of efficiency vs. bias voltage for V > $V_{depletion}$**

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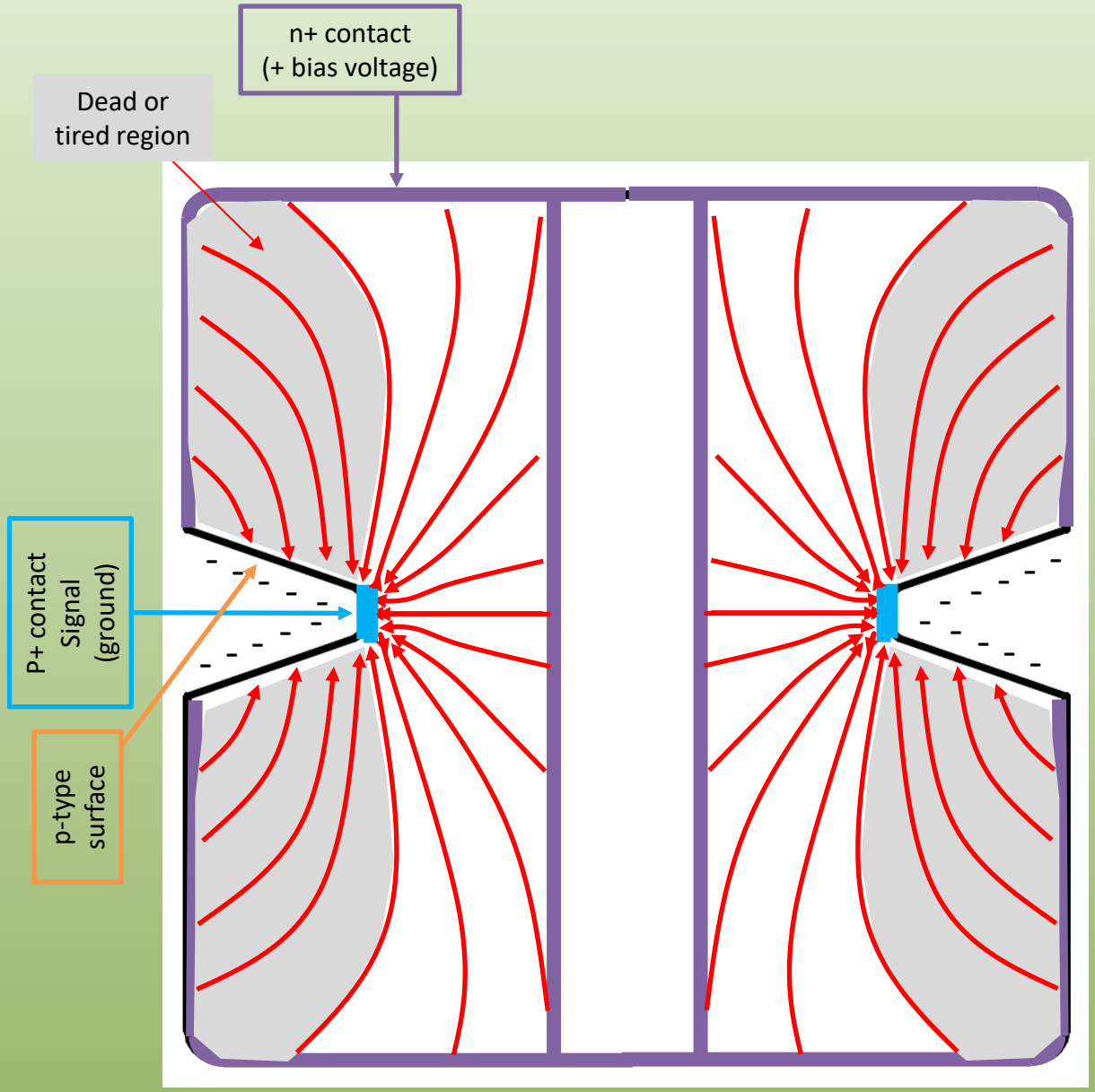
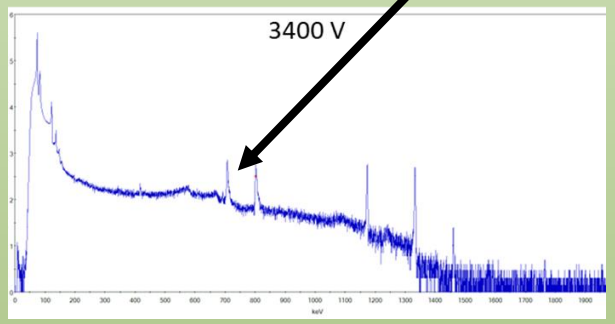



p-type surface channel

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

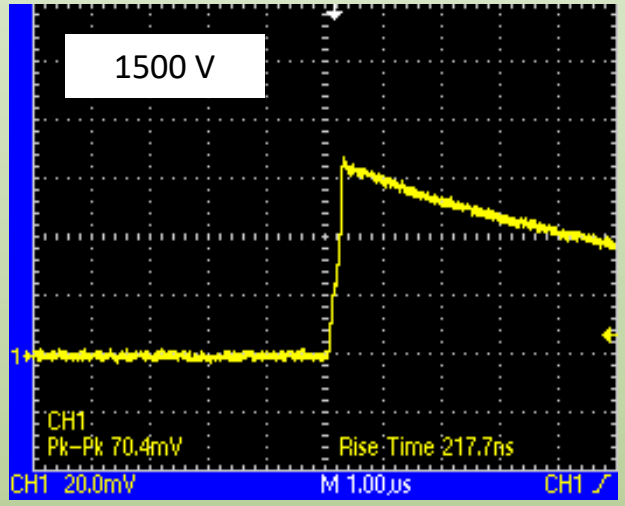



**A p-type surface channel affects a significant volume of the RCD detector**

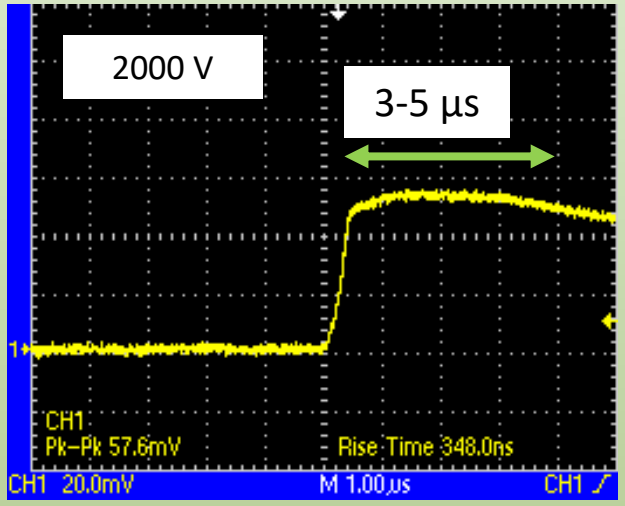
**Slow charge-carrier movement on surface**

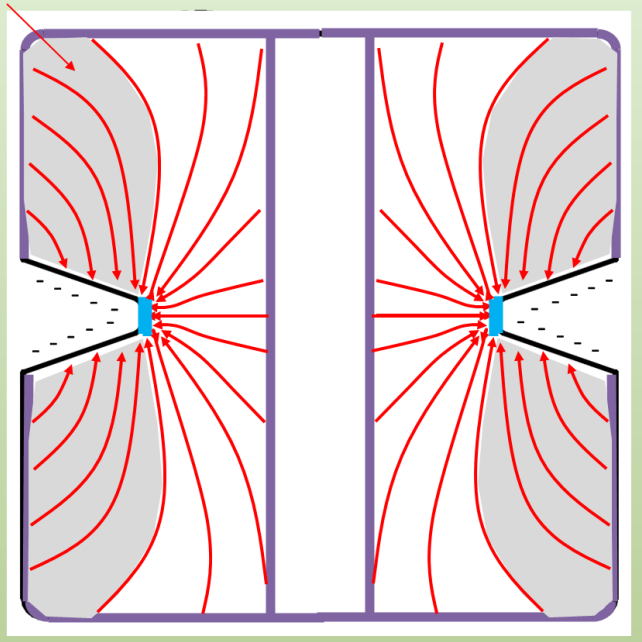
New Observation

## Normal V < $V_{depl}$

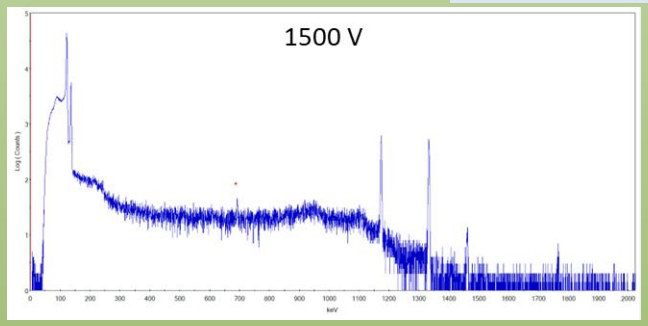


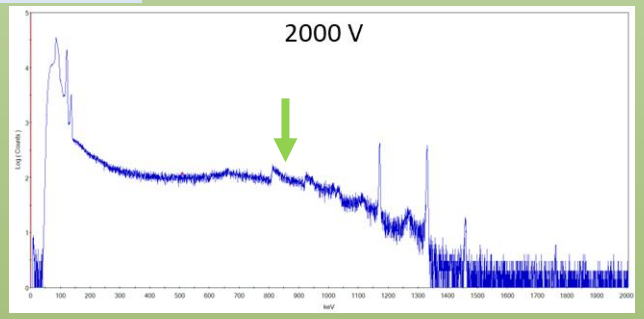

## Slow V > $V_{depl}$



$V_{depl}$ = 1600 V




**Unfortunately, this behavior repeated. The semi-fab process could not provide a sufficiently neutral intrinsic surface to suppress the issue. Always a p-type surface. V-groove is a lot of surface → Consider changing the geometry.**

# Alternative RCD geometry: A groove design

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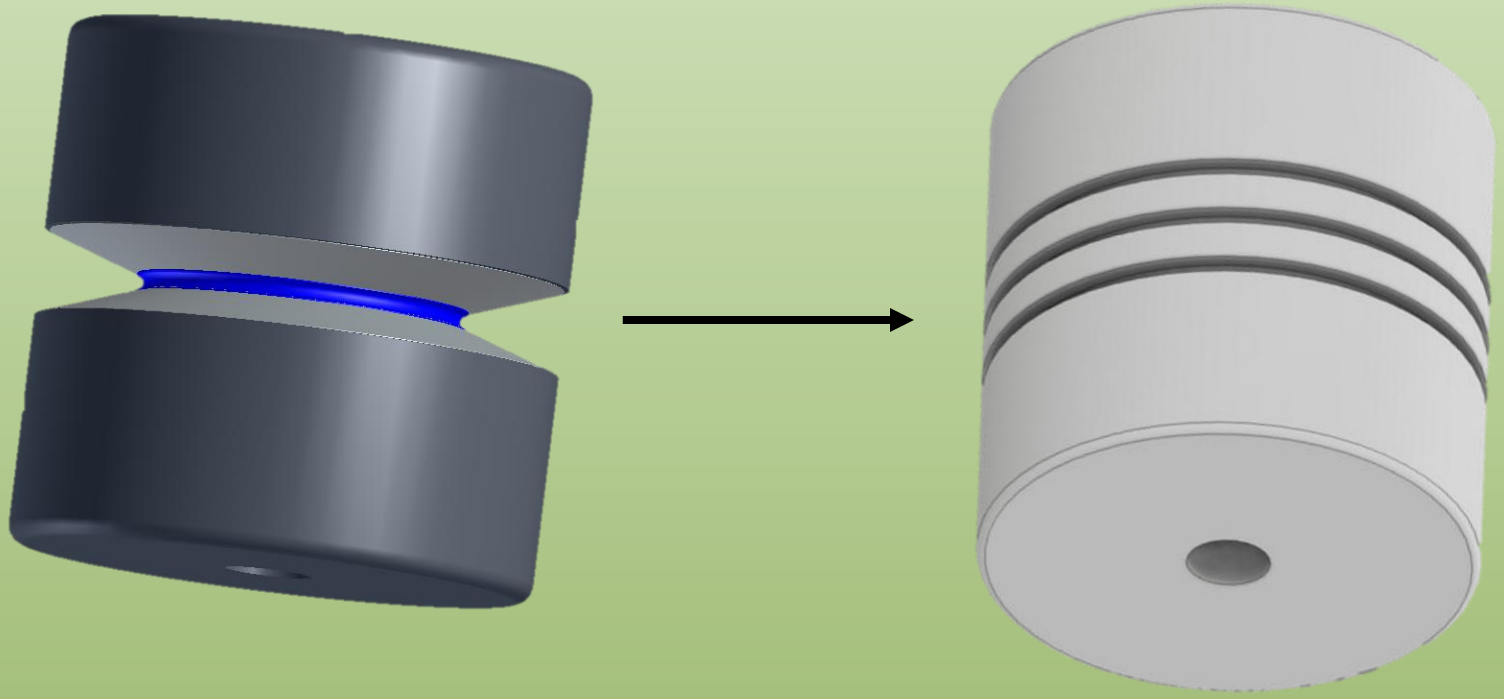

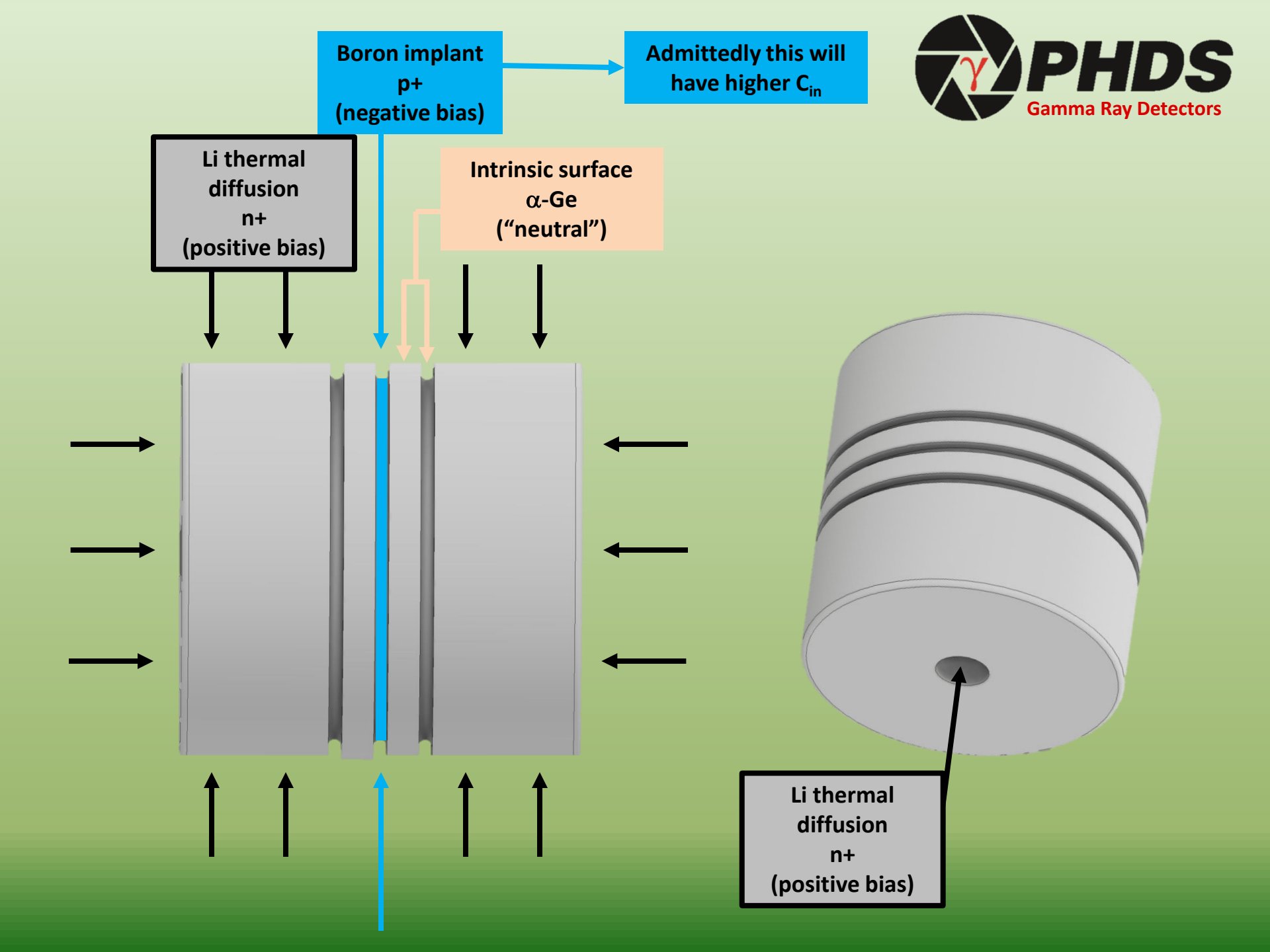
Boron implant
p+
(negative bias)
Admittedly this will have higher $C_{in}$
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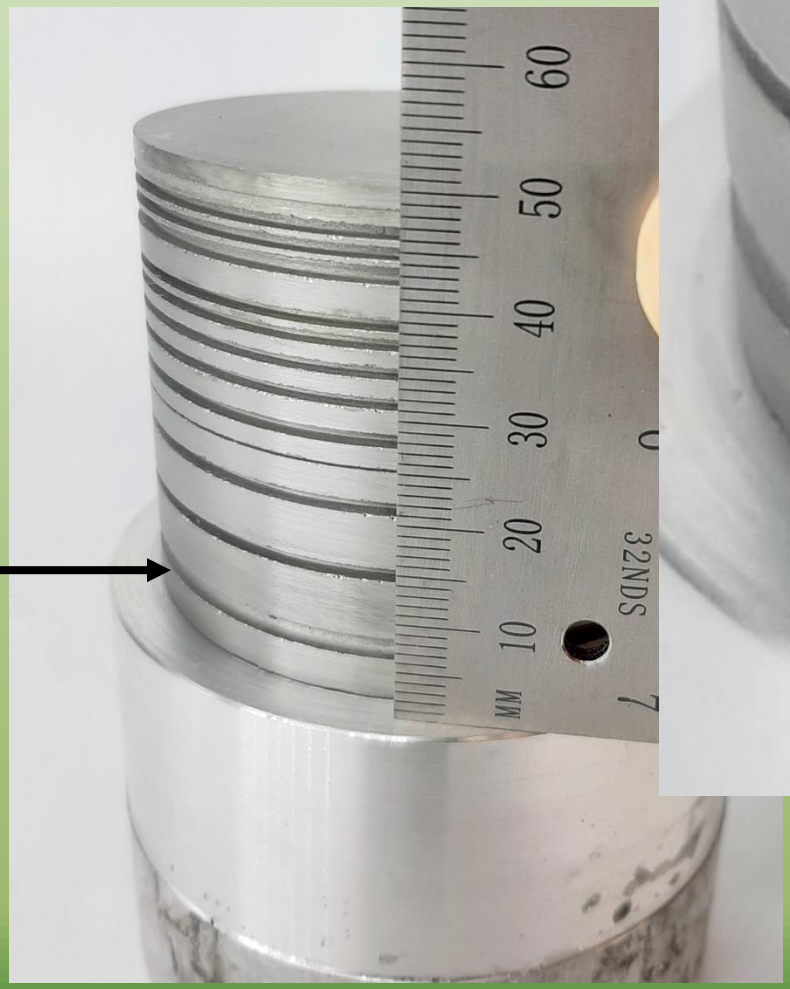
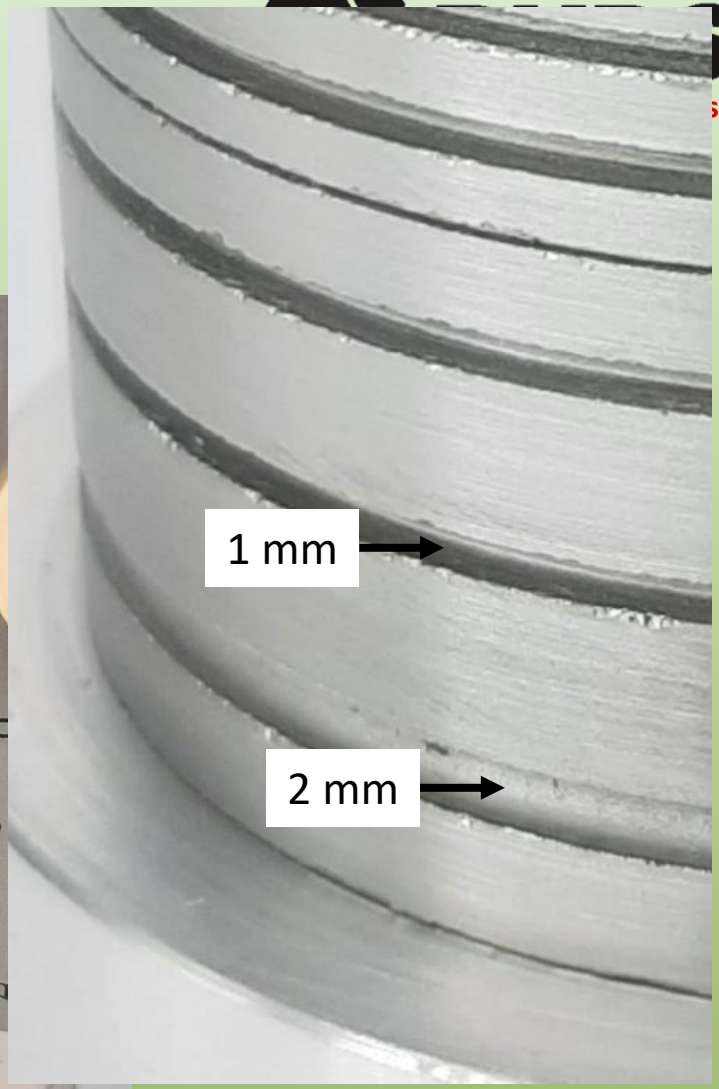
Li thermal diffusion
n+
(positive bias)
Intrinsic surface
α-Ge
("neutral")
Li thermal diffusion
n+
(positive bias)

**Figure out how to make good OD grooves (minimum chipping etc.)**

Best groove 2 mm.
Used thicker tool ().
Used speed = ().



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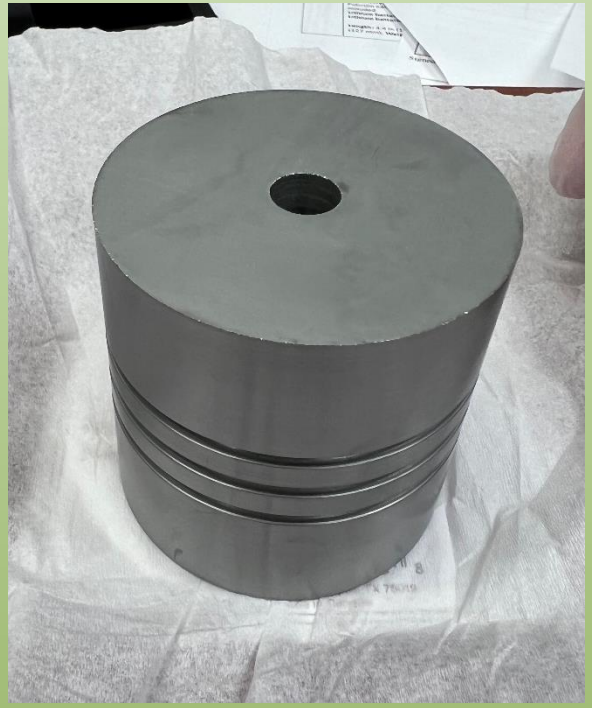
Gamma Ray Detectors

Core out 60-mm cylinder

Bore 10-mm diameter hole

Polish



OD Grind 3 Grooves

Finished

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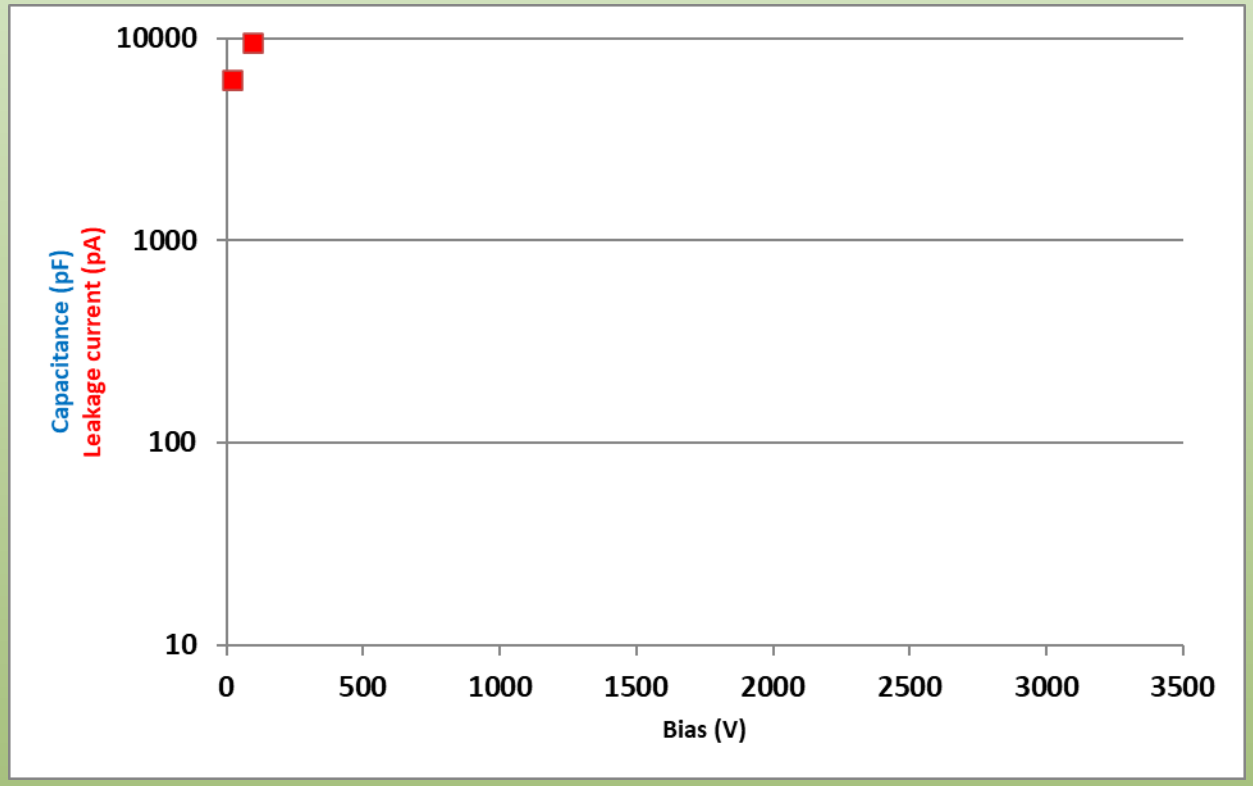
Gamma Ray Detectors

**Acid Etch rinse and Semi-fab process**

# RCD Detector Results

## Test of Detector RCD Groove Design on 20240527 <20230906> s2 c1




**Groove Detectors did not take any volts.**

**This repeated 12 times. No luck so far.**

**This was as far as we got with the RCD Semi-fab Detector work**

# RCD Crystal Results

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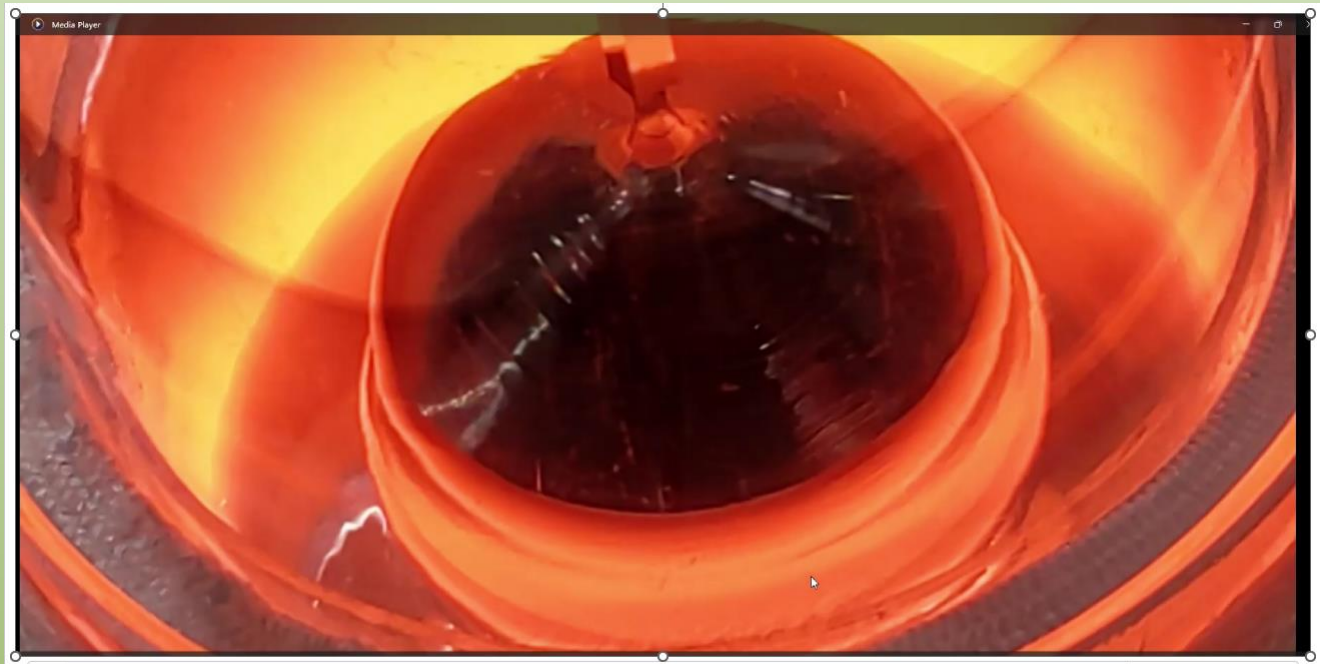
Gamma Ray Detectors



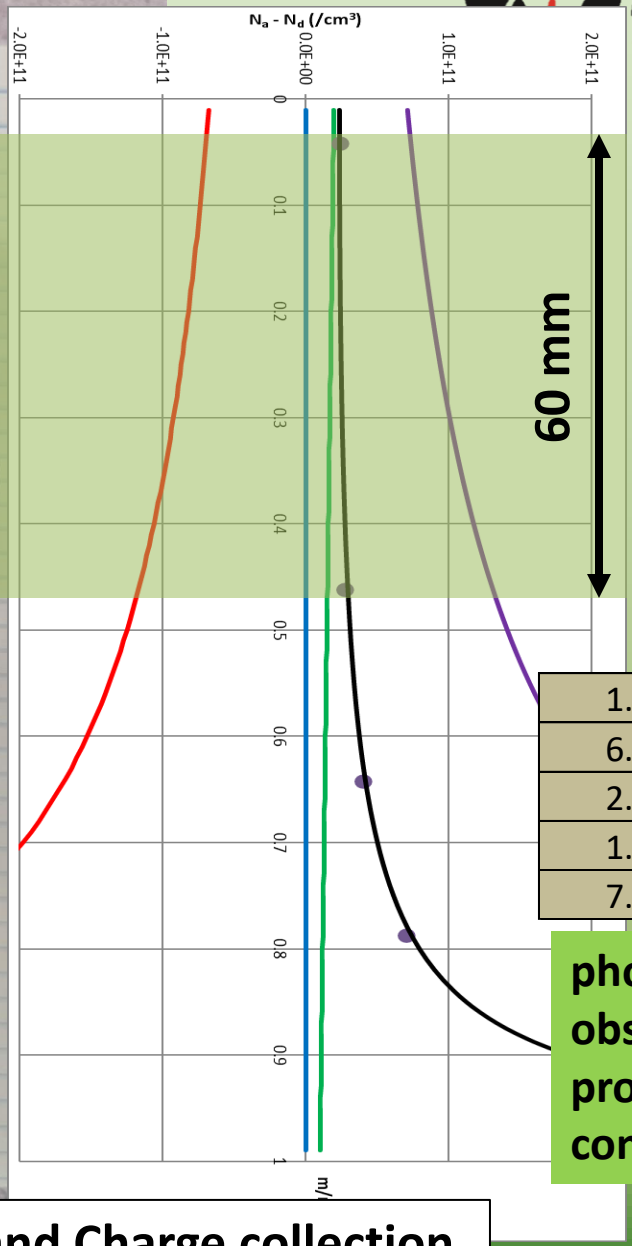

<20230906> Crystal Growth Video

# RCD Crystal Results

<20230906>

PHDS
Gamma Ray Detectors

Groove Detector Shown Earlier




2.5e10 p-type

2.8e10 p-type

| | |
|---|---|
| 1.00E+00 | Boron |
| 6.70E+11 | Phosphorus |
| 2.00E+10 | Al |
| 1.00E+10 | AL |
| 7.07E+13 | In |

**phosphorus observation provides superior consistency**

**Good RCD Crystal – Good uniformity and Charge collection**

# RCD Crystal Results

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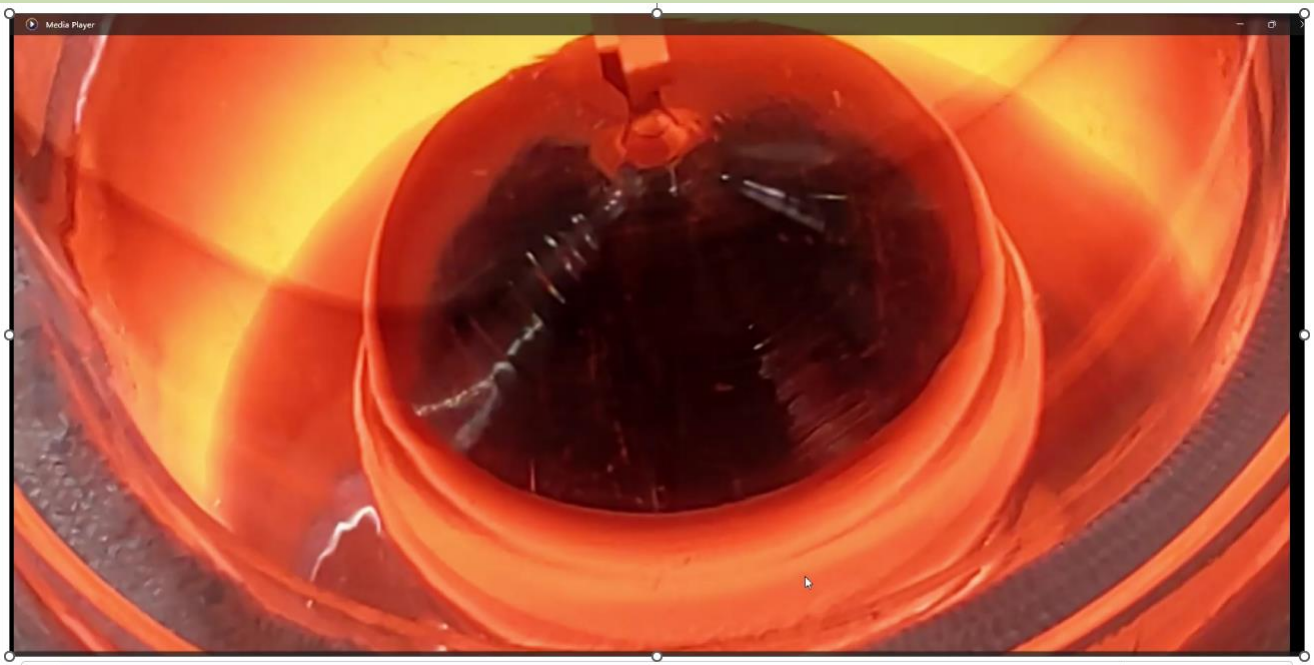
Gamma Ray Detectors




<20230906> Crystal Growth Video

# RCD Phase II Results

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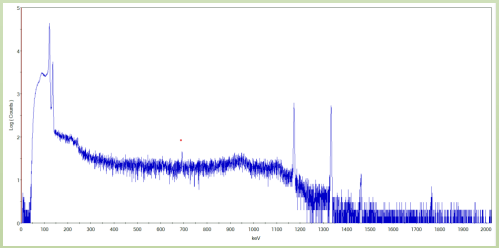
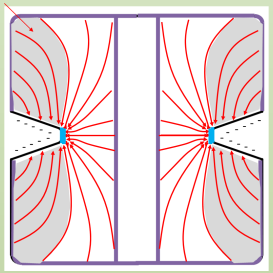
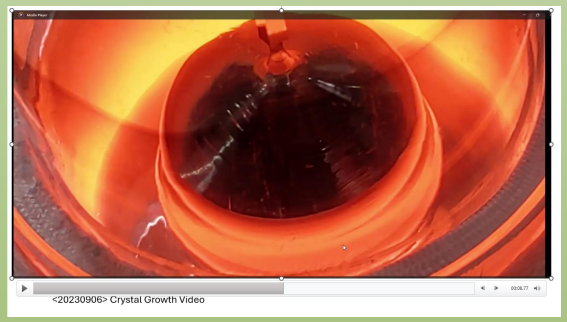
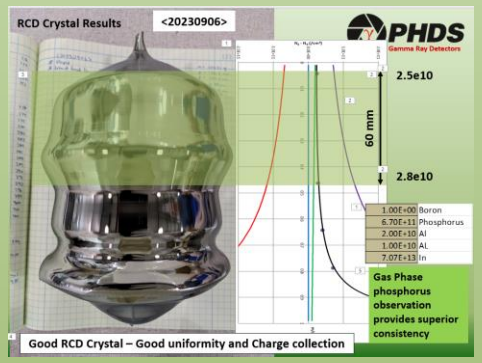
## RCD Detector Progress





## RCD Crystal Progress




## RCD Commercial Progress

# RCD Commercial Development

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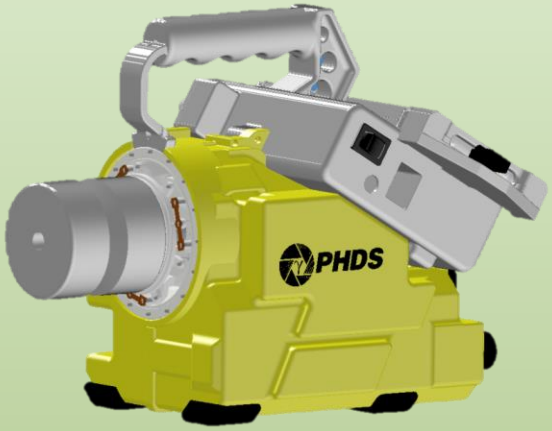
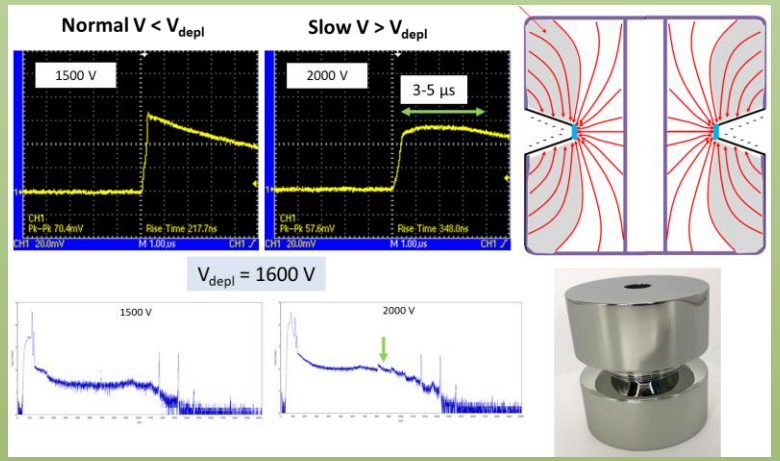




## Fulcrum-RCD – Portable, Shielded Counting System

+ RCD Crystal Development




+ RCD Semi-fab process work to neutralize p-type SC

# RCD Commercial Development

PHDS
Gamma Ray Detectors


Fulcrum


Fulcrum-40h
September
2022

# RCD Commercial Development Application

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**Fulcrum-40h**

**System is being used as “portable” or “modular” shielded counting system.**

**Fulcrum-40h inside 2” (5 cm) Pb-Shield with sample counting chamber**

**Thank you to DOE NP SBIR for the support**