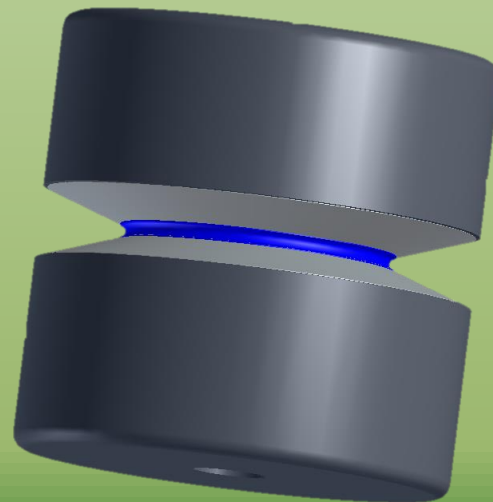


LARGE VOLUME RING-CONTACT HPGE DETECTORS (RCD)

NP SBIR Phase II Year 2

20230816 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



Science Experiment

NPX (150 lbs.)
2008 Laboratory



NP Imager

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

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

Frontiers of Nuclear Physics

Frontlines of Nuclear Security

PHDS Co. now manufactures and sells HPGe products



New Fall 2022

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.phdsco.com sales@phdsco.com

NP Imager

Nuclear Physics - Radiochemistry Imaging Spectrometer



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



Fulcrum-40h

Hand Portable HPGe Gamma Ray Spectrometer



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



GeGI

Germanium Gamma-Ray Imaging HPGe Spectrometer



2550 300 W-hr External battery

Specifications subject to change



Fulcrum

Hand Portable HPGe Gamma Ray Spectrometer



2550 300 W-hr External battery

Specifications subject to change



LoPro

Low Profile Hand Portable HPGe Gamma Ray Spectrometer



2550 300 W-hr External battery

Specifications subject to change



NP Imager

Nuclear Physics - Radiochemistry Imaging Spectrometer



2550 300 W-hr External battery

Specifications subject to change



Fulcrum-40h

Hand Portable HPGe Gamma Ray Spectrometer



2550 300 W-hr External battery

Specifications subject to change



Detect, Identify, Locate, Quantify

Identify, Quantify, Fast Cool down

Detect, Identify Special Apps

Radiochemistry, Rare Isotopes

Identify, Quantify, High Sensitivity

Applications Served by these Products



Nuclear Security 65-75 %

Research 25-35%

Ray Detectors



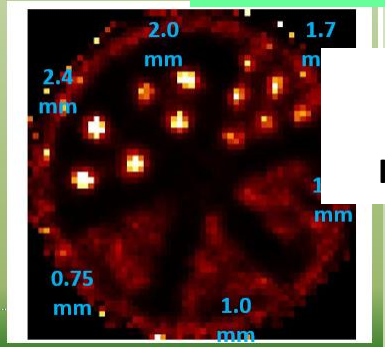
Nuclear Response Team



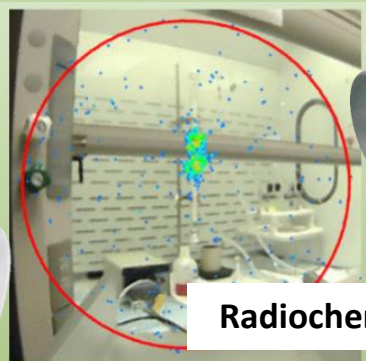
CBRN Team



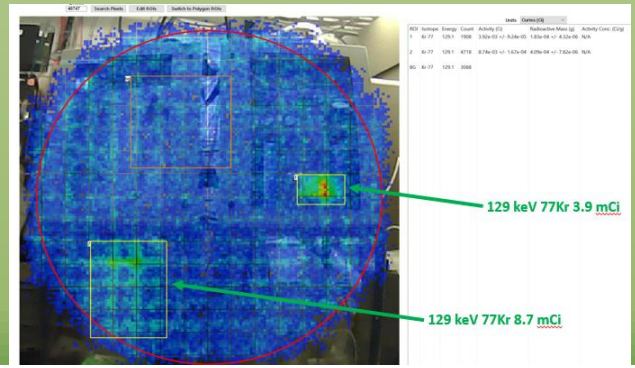
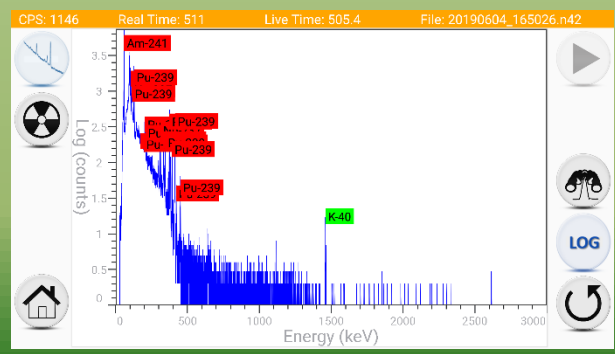
Nuclear Materials Management + D&D



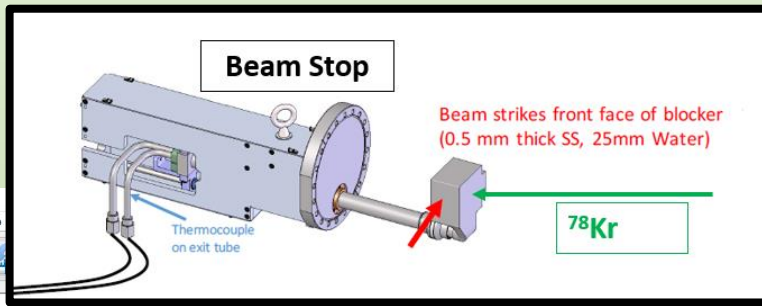
Radiochemistry, Imaging R&D and Isotope Production



Radiochemistry



R&D Isotope production / harvesting



Imager - [20190510_230705-4GMT-Kry77_129keV.img]
File Acquire View Tools Options Show Window Help

Threshold 0 Distance(cm) 1.700 +/-

46747 Search Pixels Edit ROIs Switch to Polygon ROIs

Isotope	Energy (keV)
Ann.	511.0
<input checked="" type="checkbox"/> ⁷⁷ Kr	129.1
<input checked="" type="checkbox"/> ²³² Th	85.4
Auto:138	137.8
NEU:847	845.9
Auto:143	143.3
Auto:286	286.0
Auto:375	375.1
Auto:417	417.1
Auto:635	635.1
<input checked="" type="checkbox"/> ²³² Th	911.2
Auto:820	819.7
Auto:900	900.4
<input checked="" type="checkbox"/> ²³² Th	1501.6
Auto:1041	1041.1
Auto:1098	1097.7
Auto:1294	1294.4
Auto:2019	2018.8
Auto:2114	2114.0

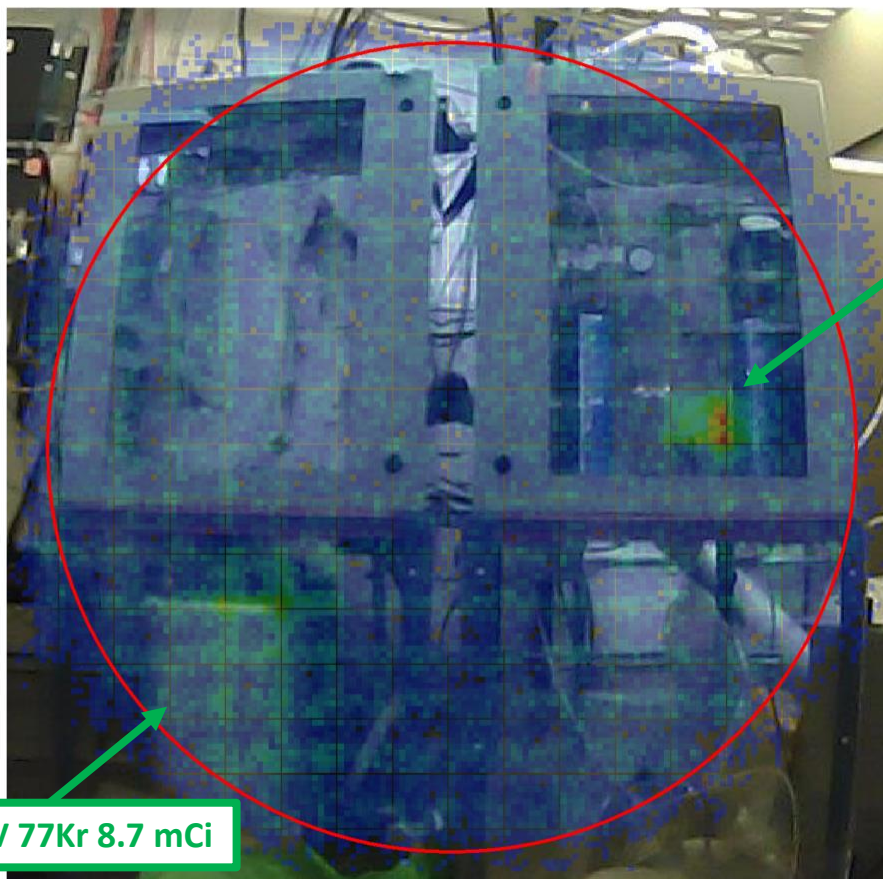
Intervening Materials

Material Density... Thick...

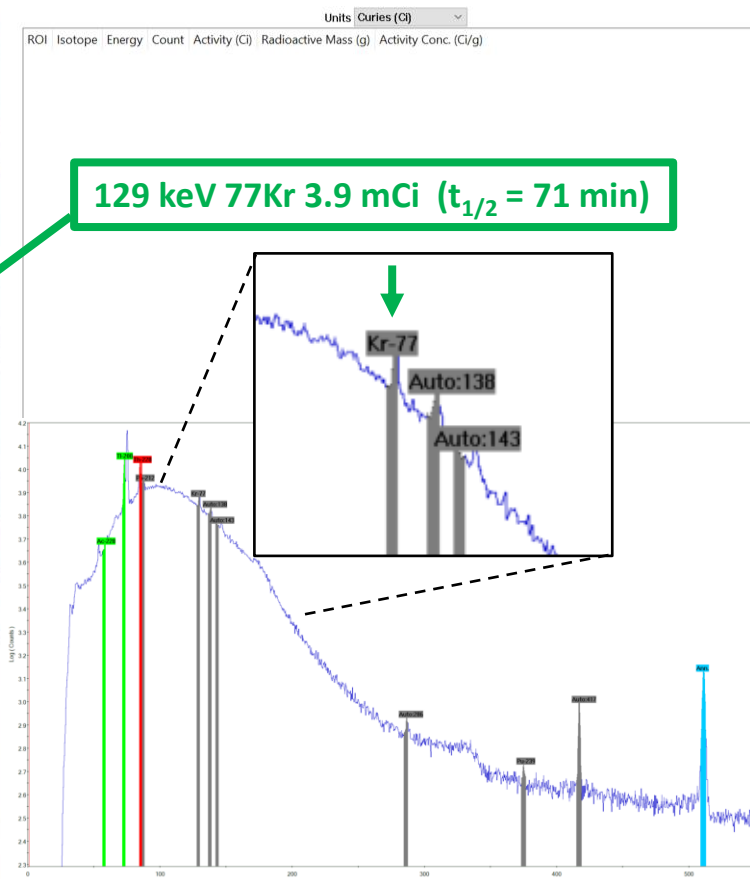
ROI Materials

ROI Material Density... Thick...

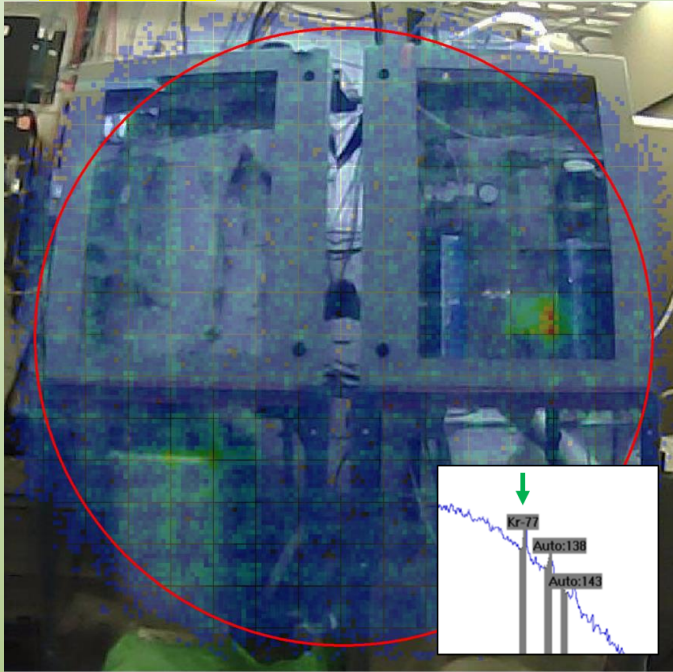
There are no items to show in this view



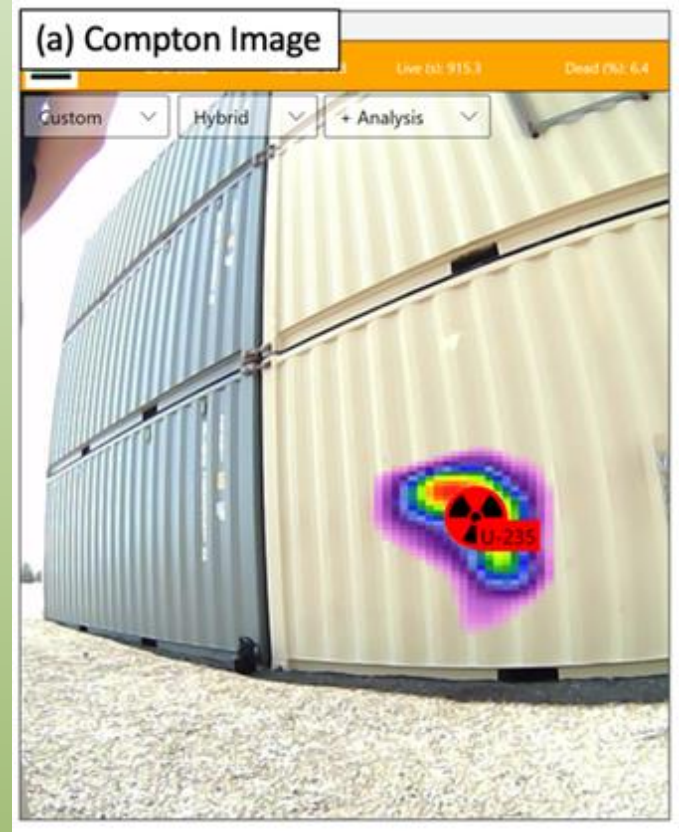
129 keV 77Kr 8.7 mCi



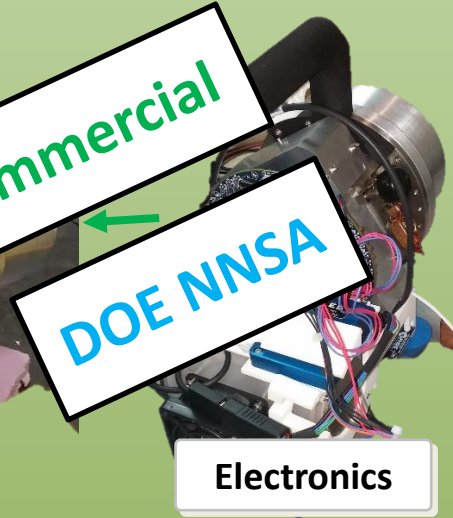
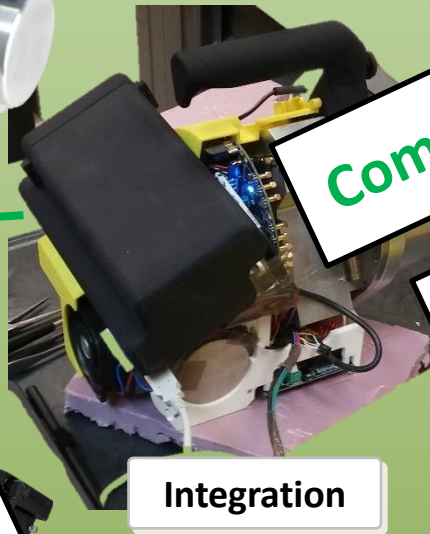
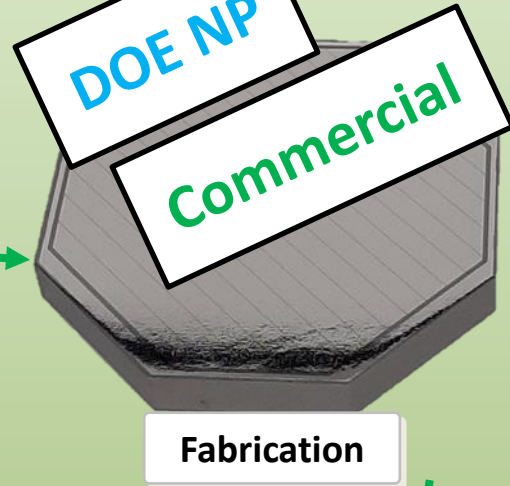
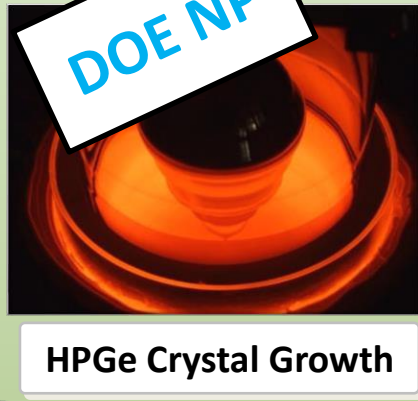
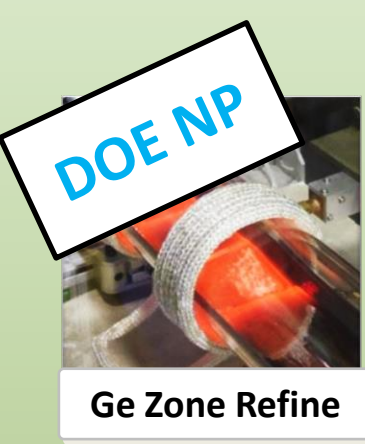
Frontiers of Nuclear Physics



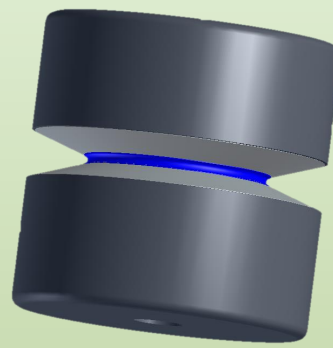
Frontlines of Nuclear Security



PHDS Co. vertical manufacturing



DOE NP Grants, Sales and Product Performance



Ring Contact Detector

RCD Features

Largest Mass

Fewest Detectors per kg of Ge

Lowest background (connections, mounting etc.)

Majorana + LEGEND

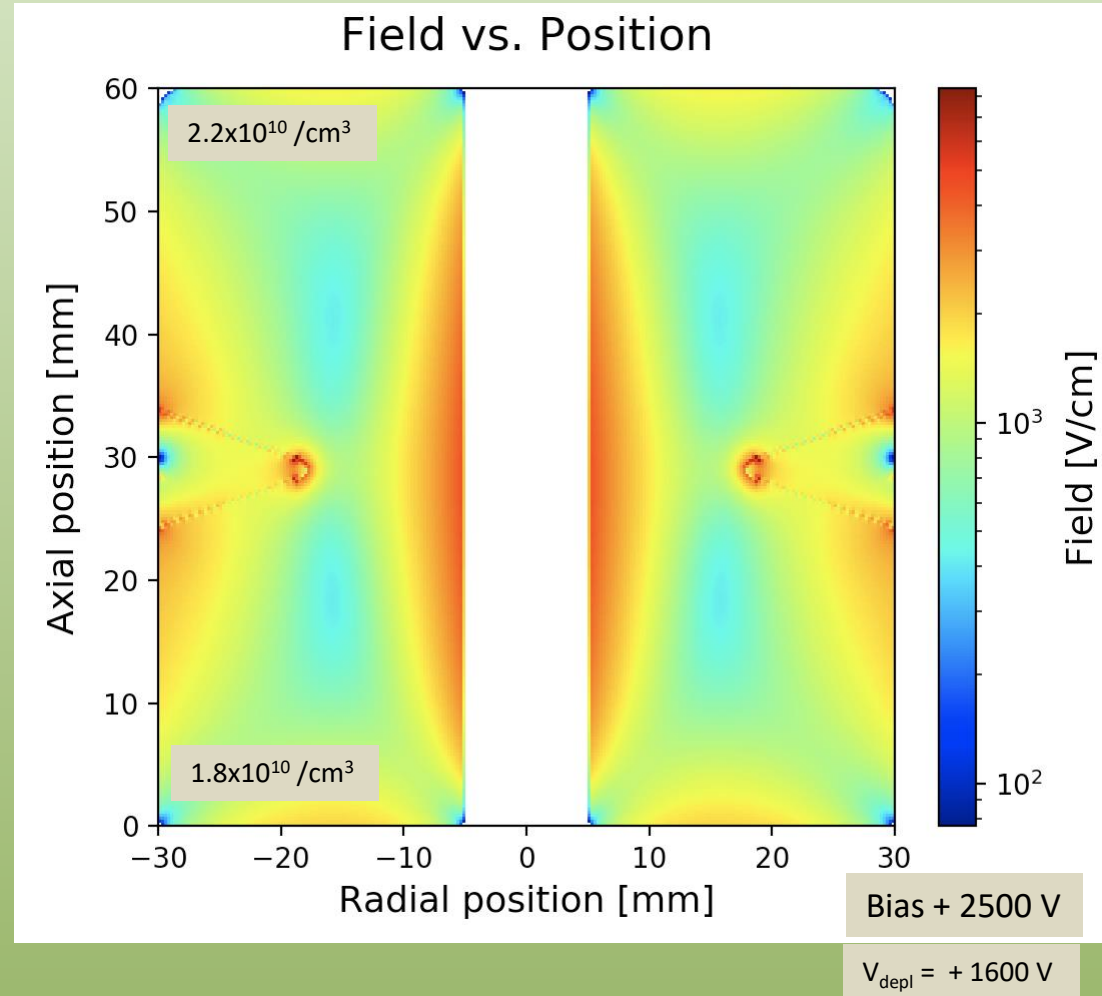
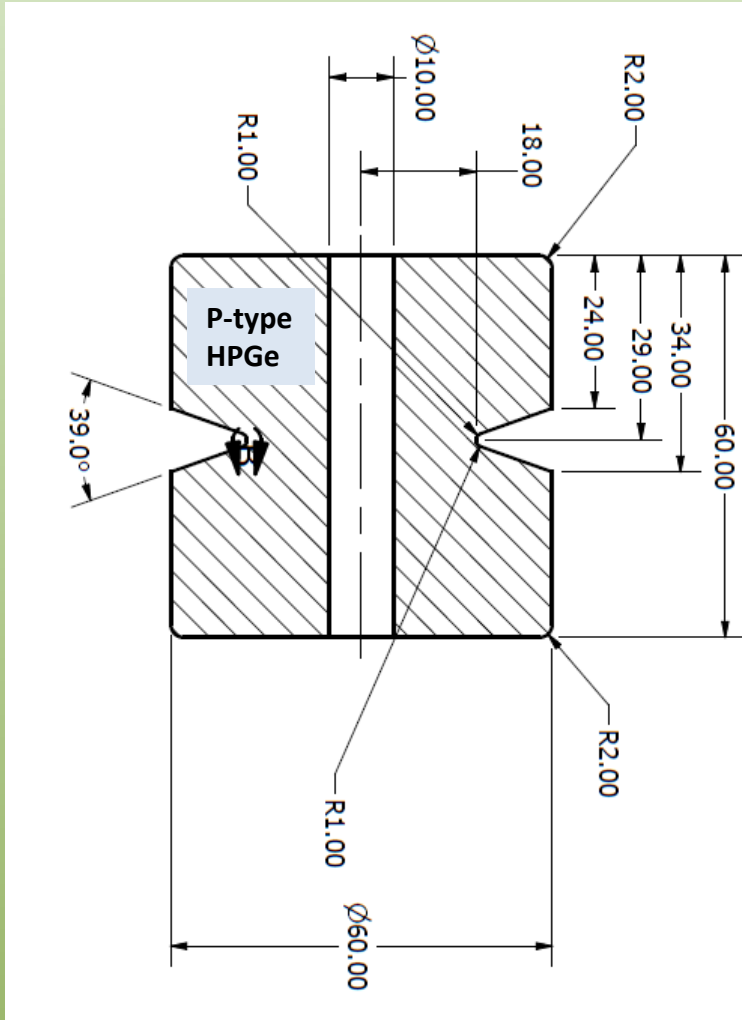
High efficiency – R&D and Counting Labs

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

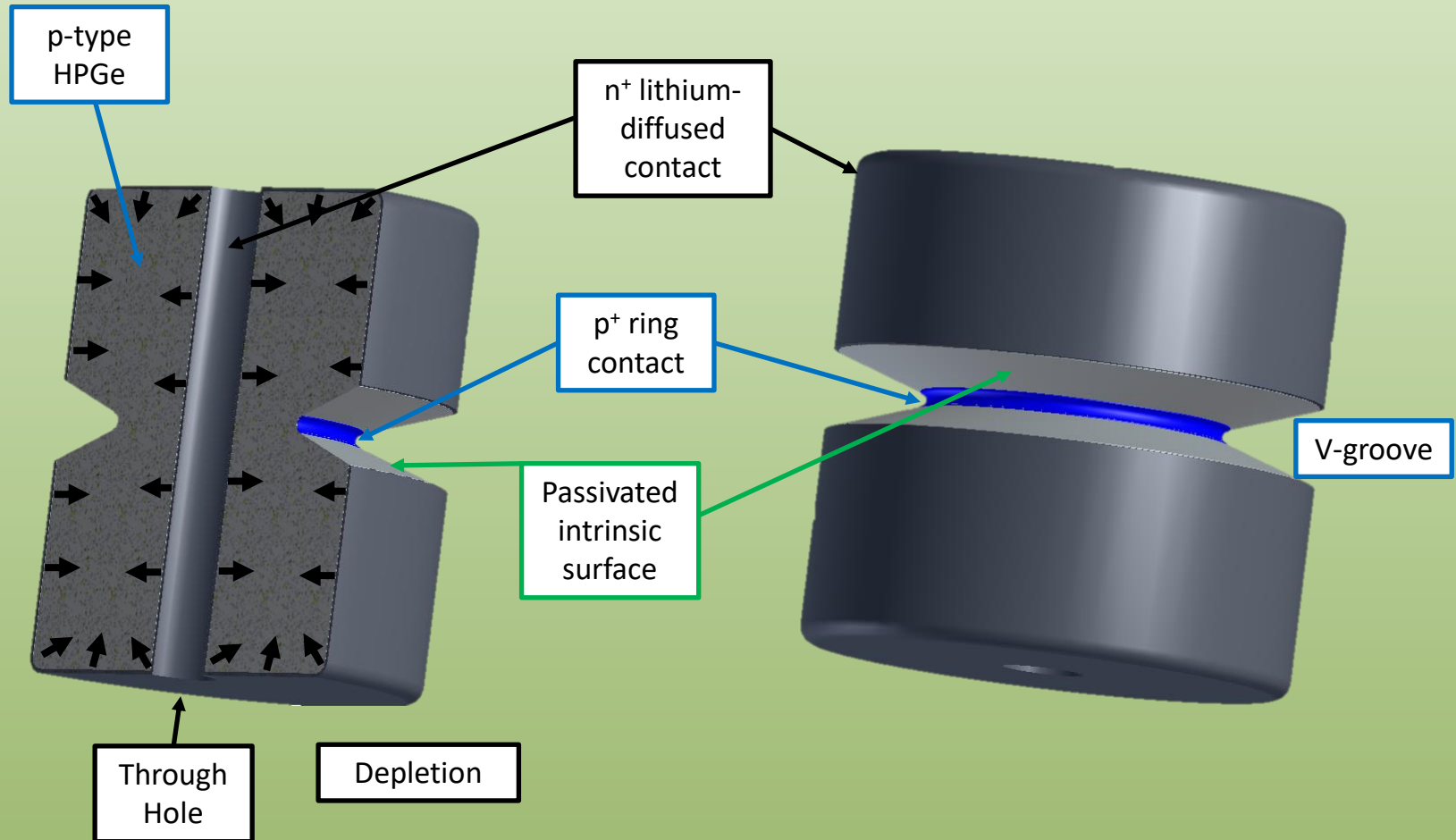
No significant increase in capacitance (noise)

Ring Contact Detector (RCD) Concept – David Radford



Electrostatics Calculations show
scalability up to 8 kg of depleted HPGe

Ring Contact Detector (RCD) Concept – David Radford



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



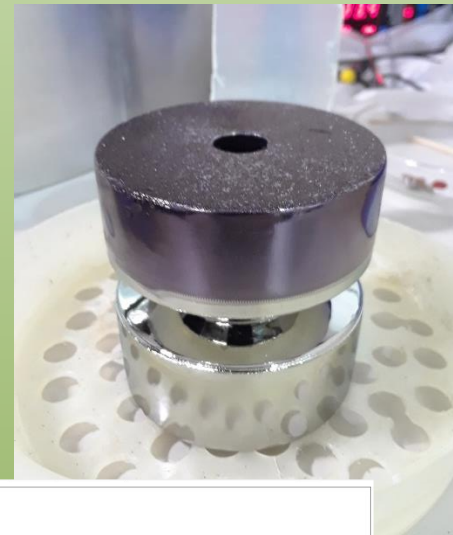
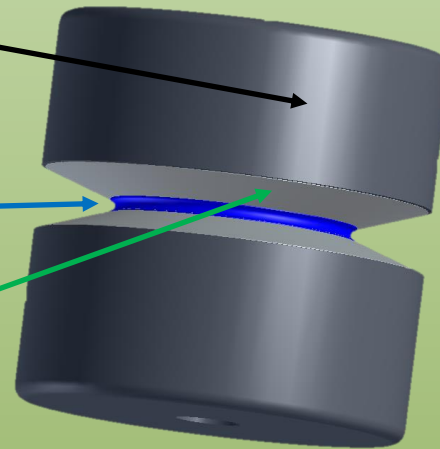
2. Semiconductor Detector Processing

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

n⁺ lithium-diffused contact

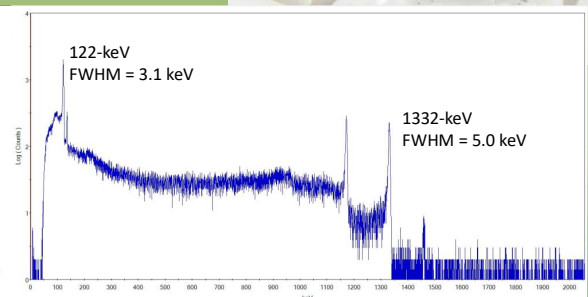
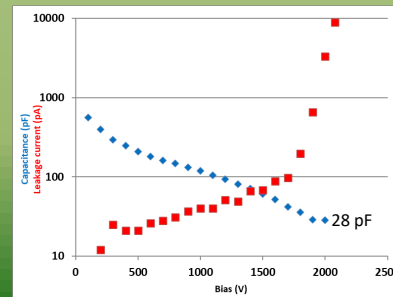
p⁺ ring contact

Passivated intrinsic surface

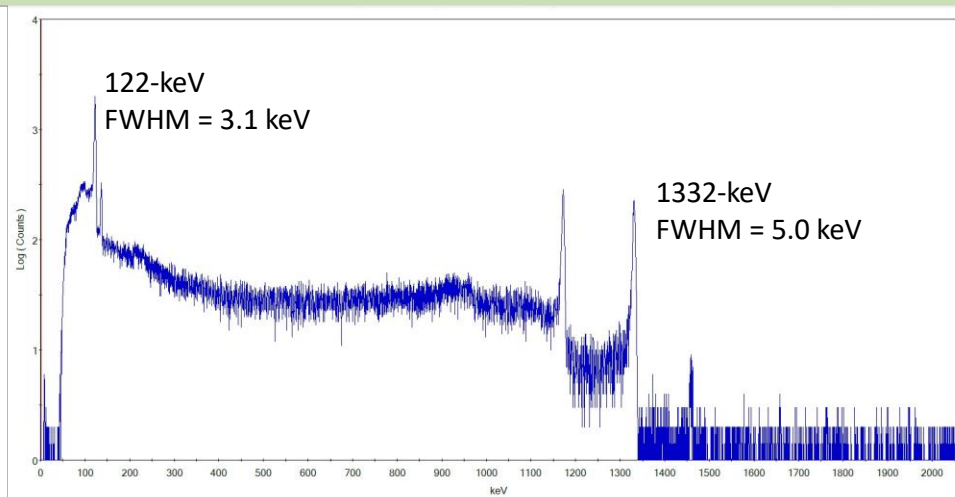
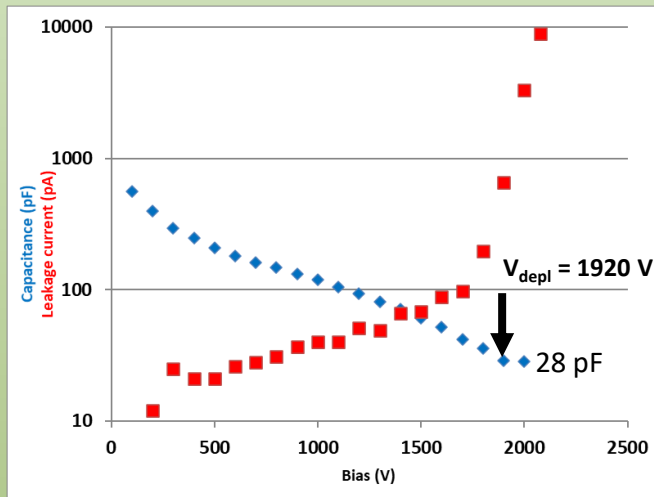


3. Crystal Growth

- Uniformity
- Length of HPGe Region
- Charge Collection



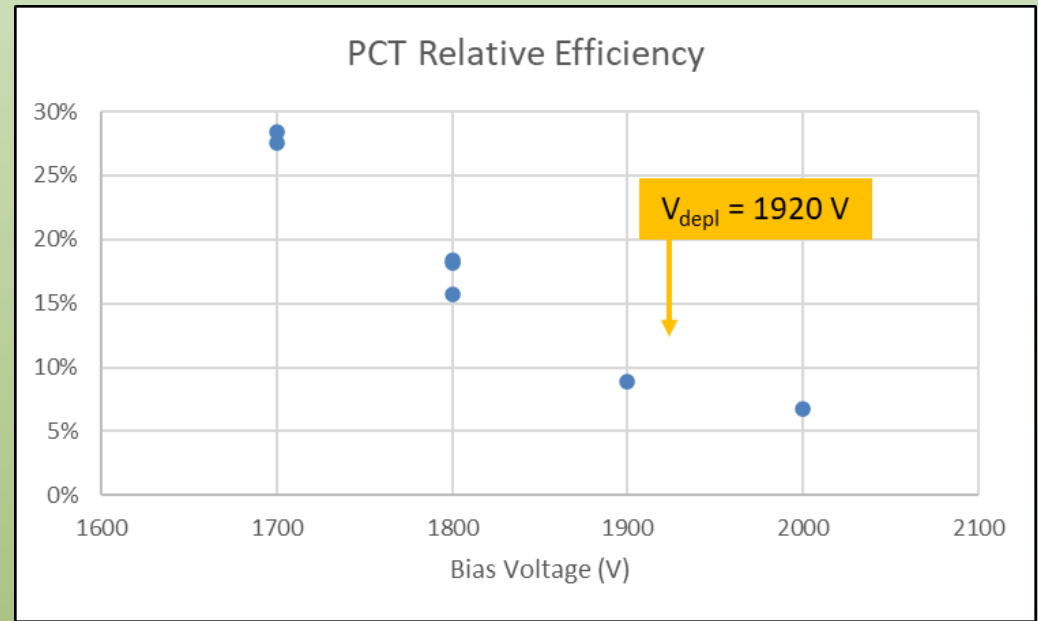
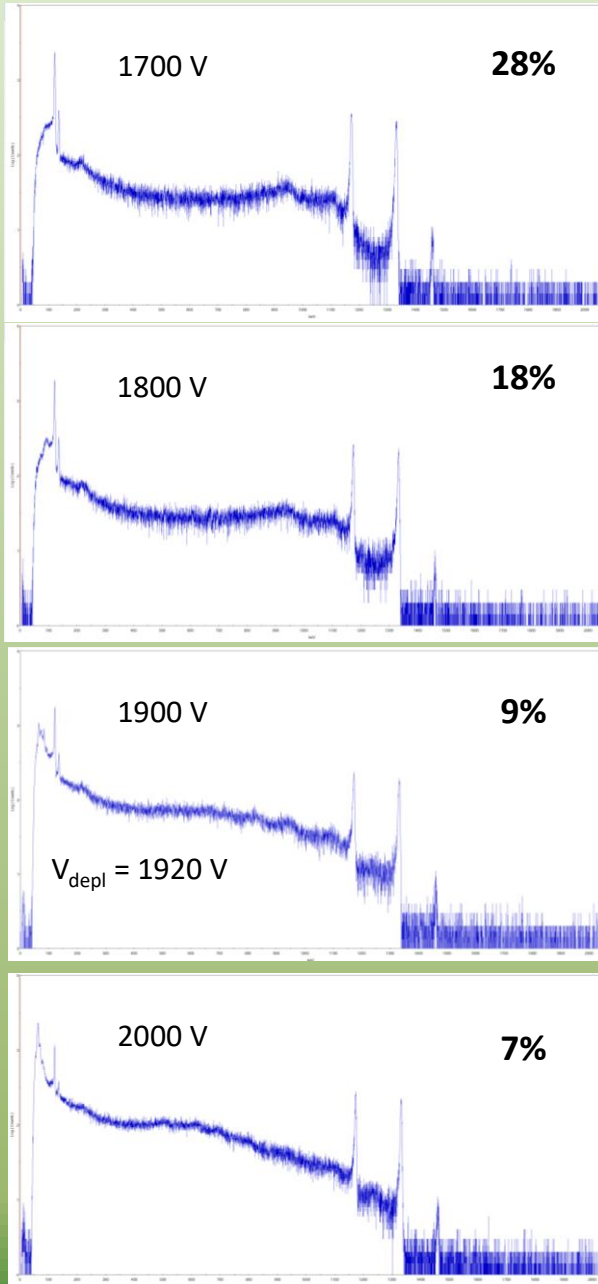
2. Semiconductor Detector Processing RCD detector testing and again.



Progress points

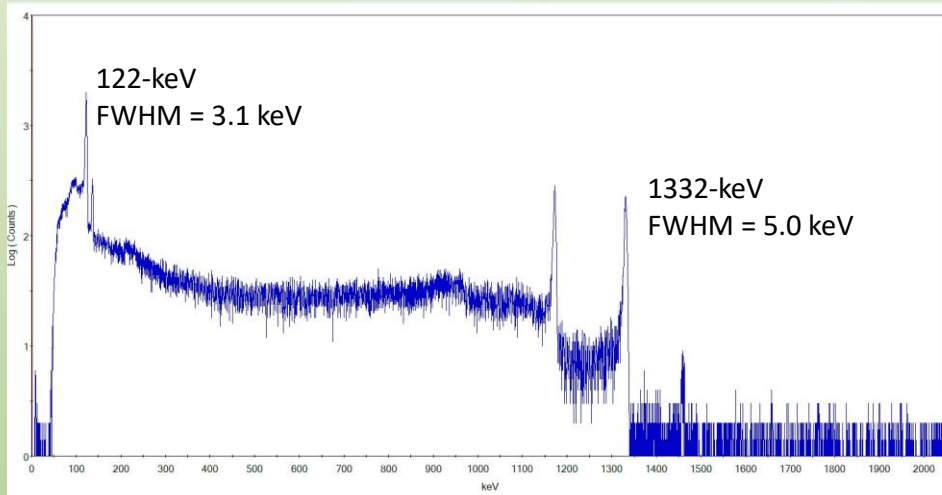
- Depleted Detector – 1920 V is reasonable
- Capacitance is reasonable
- The RCD geometry can deplete and function as a gamma-ray detector
- Spectroscopy is so – so

Semiconductor physics observation



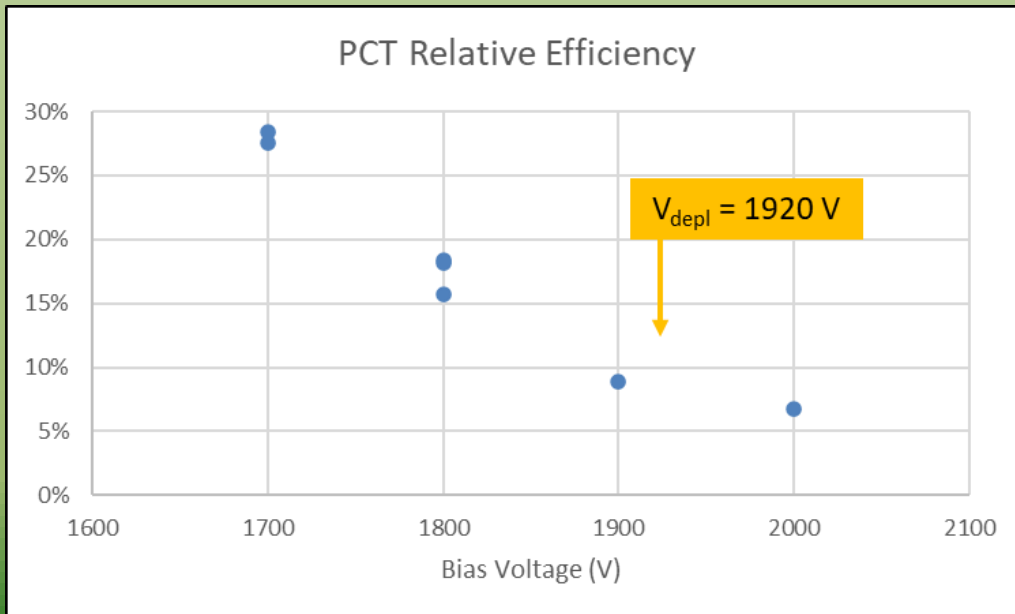
The full-energy 1332-keV peak efficiency decreases dramatically with increasing bias near V_{depl} – an interesting result (implant first, passivation second)

Spectroscopy



- Get a crystal from Umicore to address spectroscopy
 - Compare PHDS to Umicore wrt RCD detector performance

Loss of efficiency

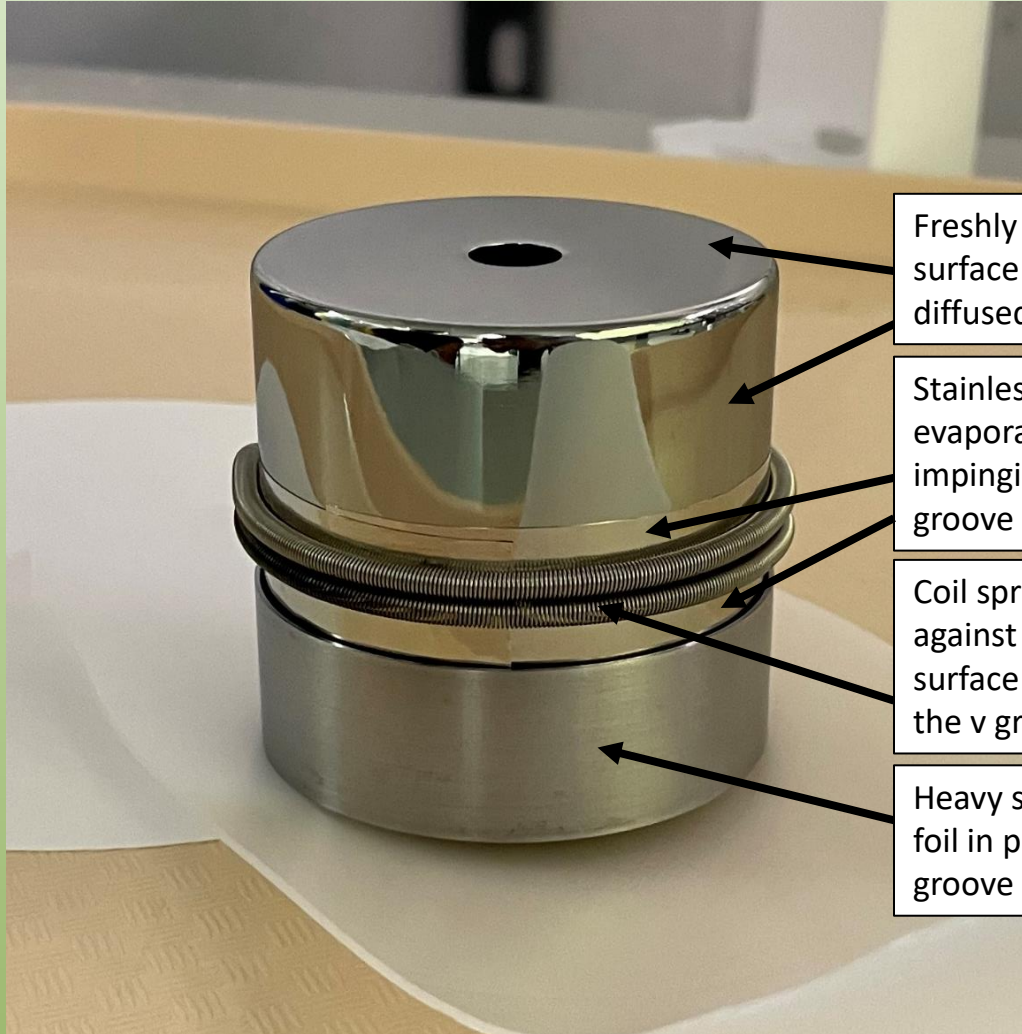


- Change the order of operations in the fabrication to affect the loss of efficiency
 - Implant first, passivation second
 - Passivation first, implant second

Umicore 3000116784-000001 Crystal Made into an RCD



Umicore 3000116784-000001 Crystal Made into an RCD – Lithiation



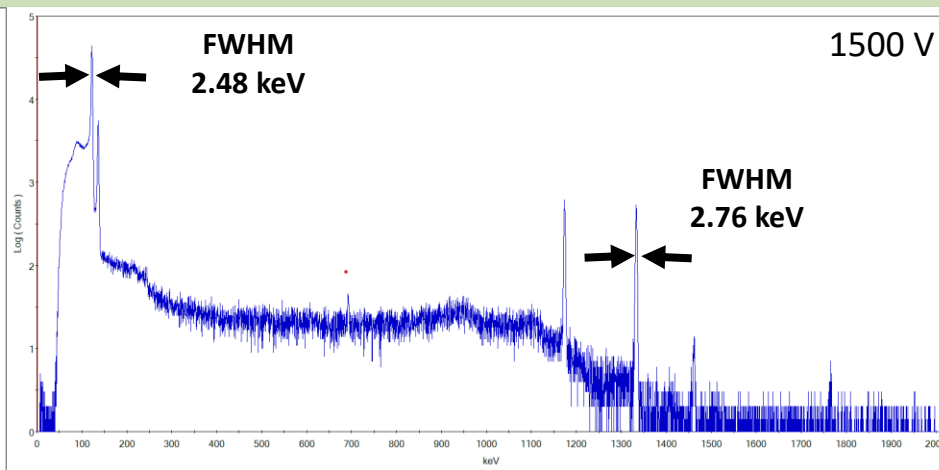
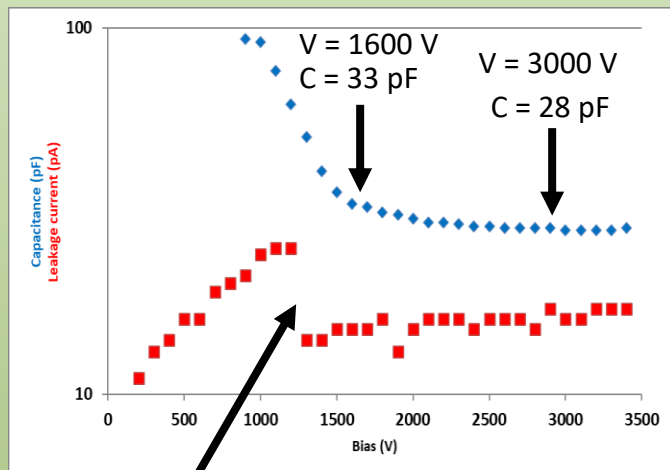
Freshly etched germanium surface to be thermally diffused with lithium

Stainless steel foil to block evaporated lithium from impinging on the intrinsic v-groove

Coil spring to hold foil tightly against the cylindrical surface of the detector over the v groove

Heavy steel cylinder to hold foil in place beneath the v-groove

Umicore 3000116784-000001 Crystal Made into an RCD



This is not so normal. !!??

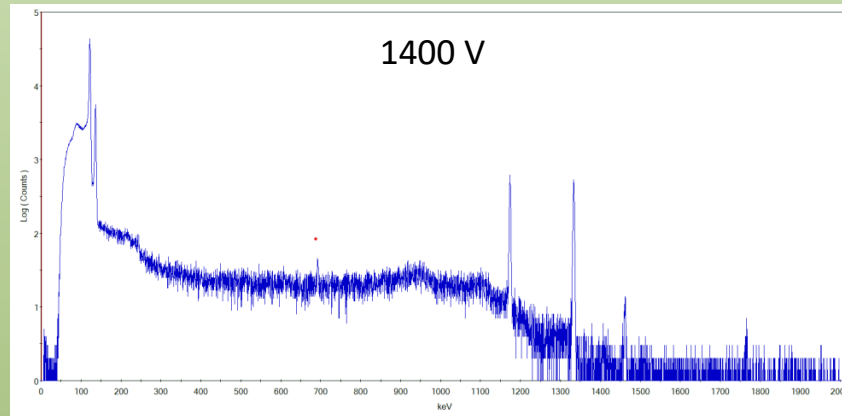
IR leakage pinching off from the ring contact

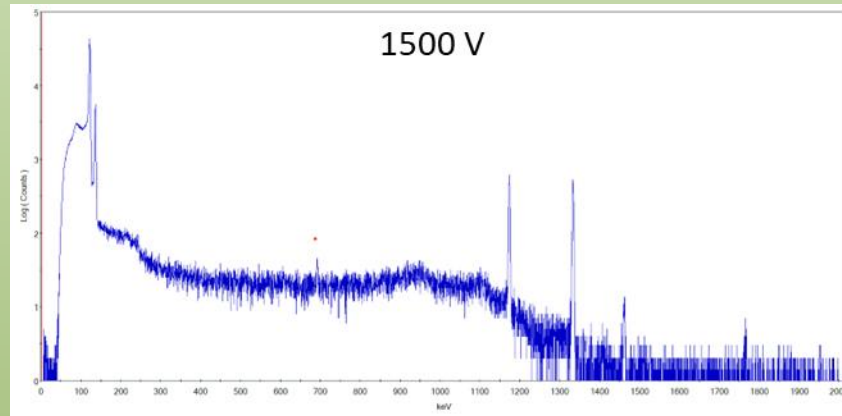
Better!

The Umicore crystal is better.
If we improve charge collection, this design has merit wrt spectroscopy

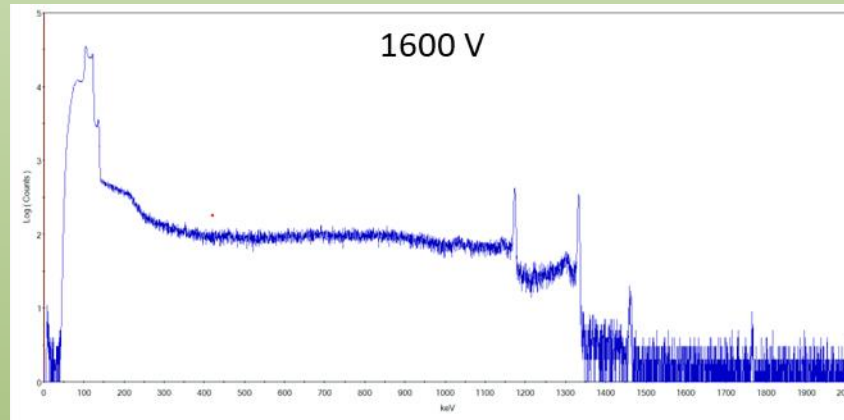
Spectroscopy shown at 1500 V

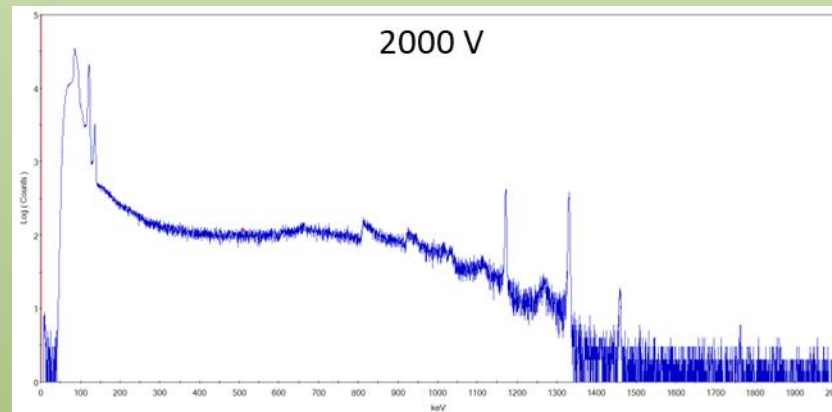
Umicore 3000116784-000001 Crystal Made into an RCD

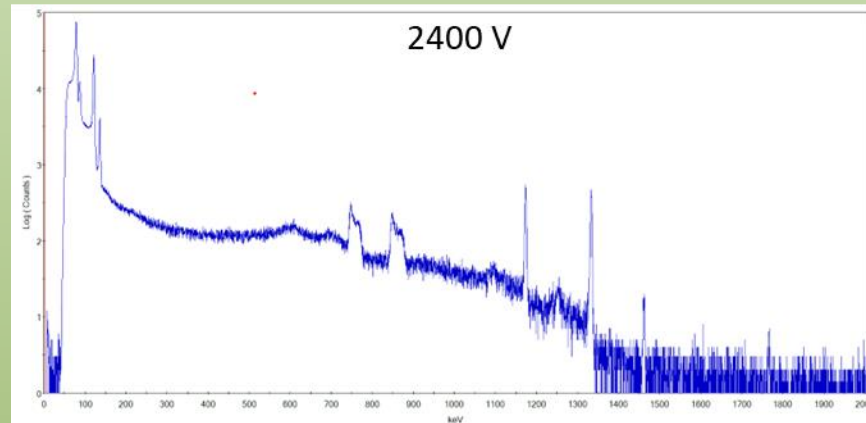


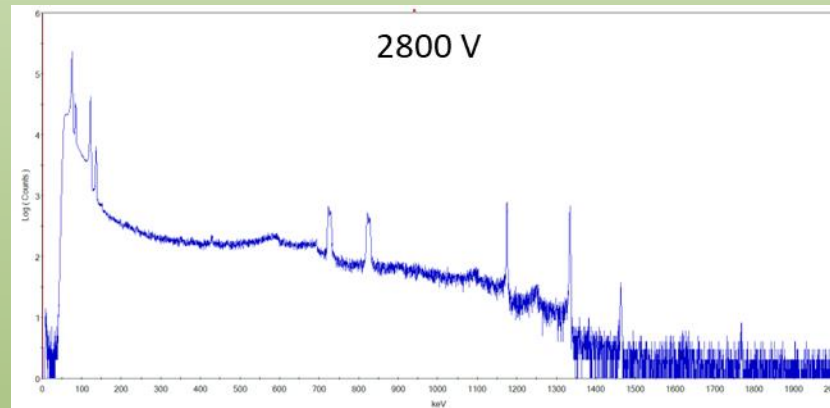


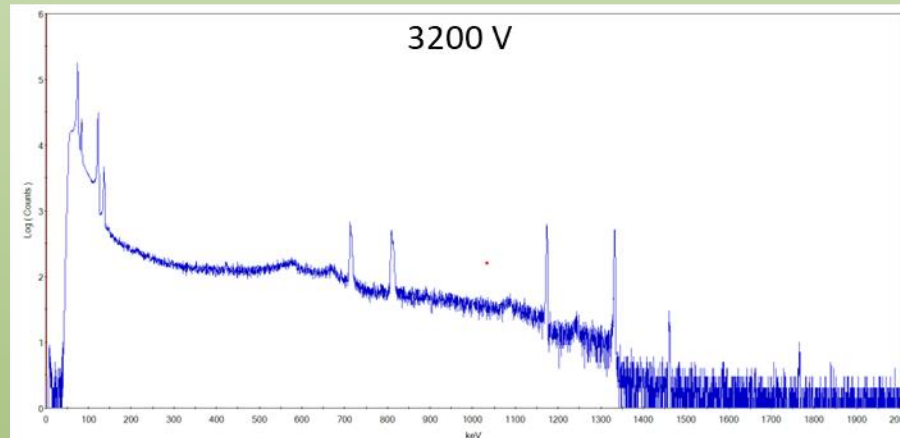
Vdepl = 1600 V

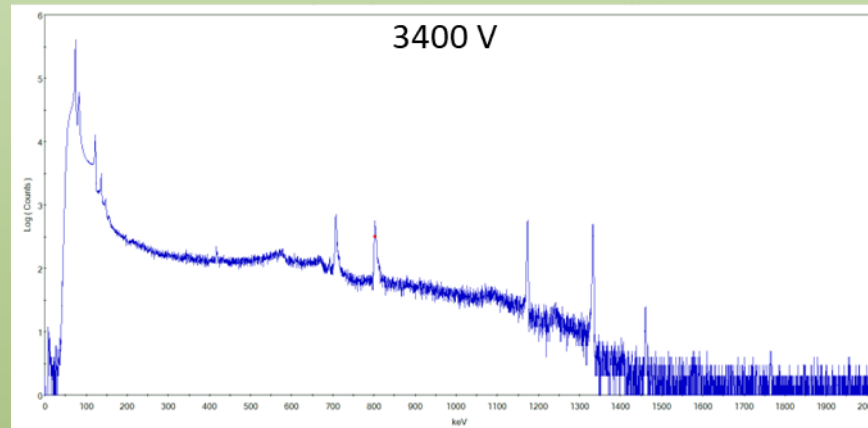




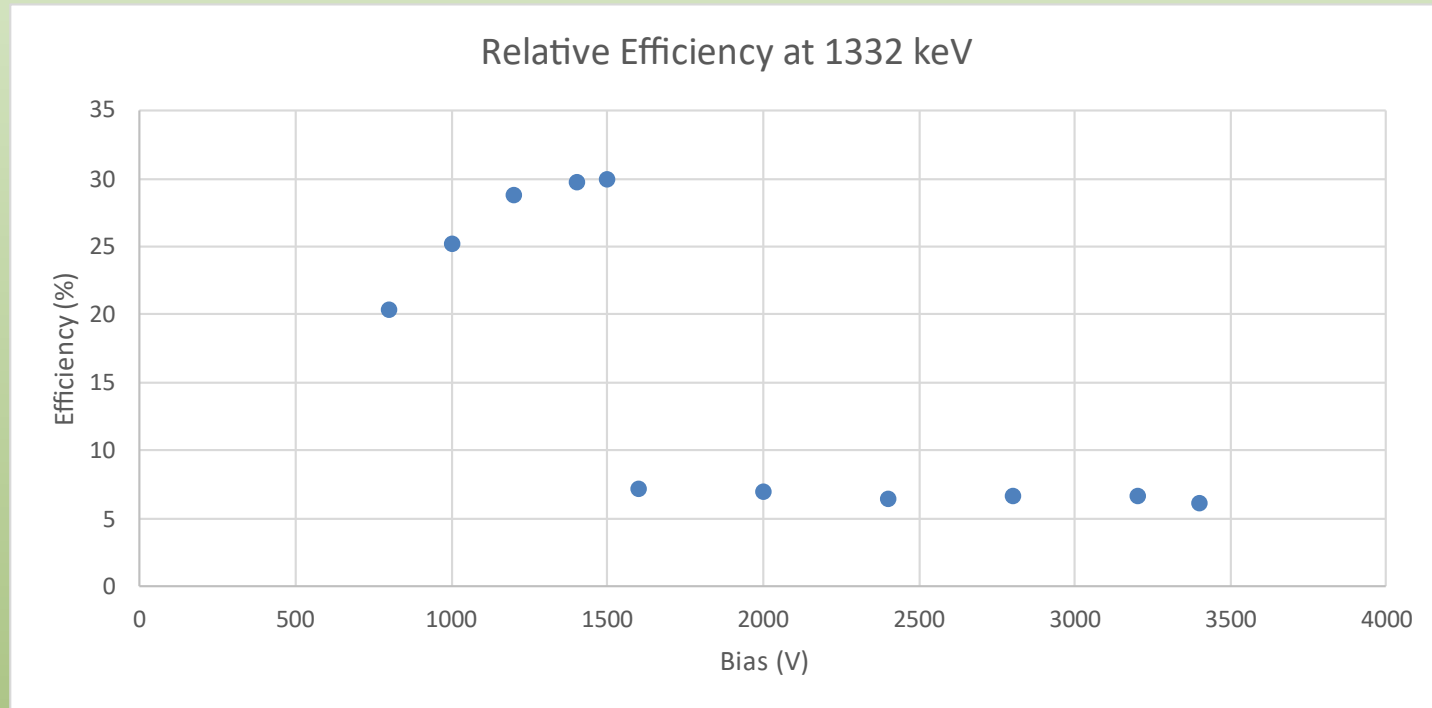








Loss of efficiency



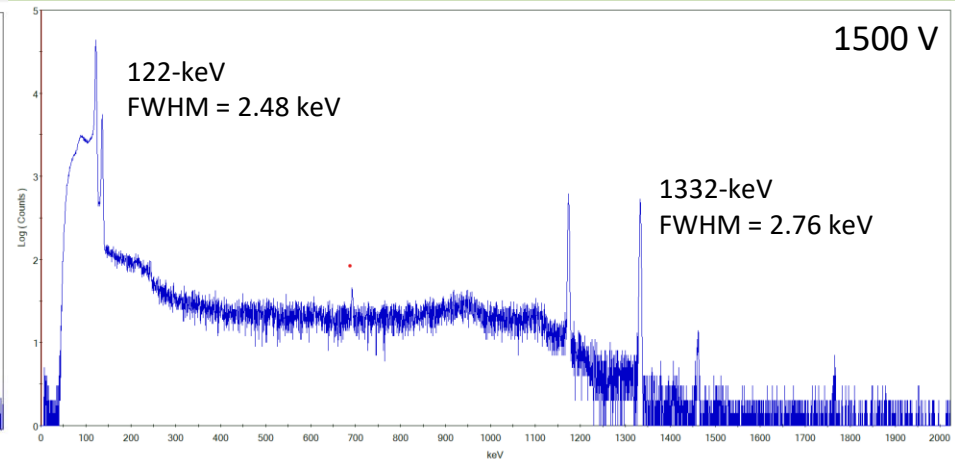
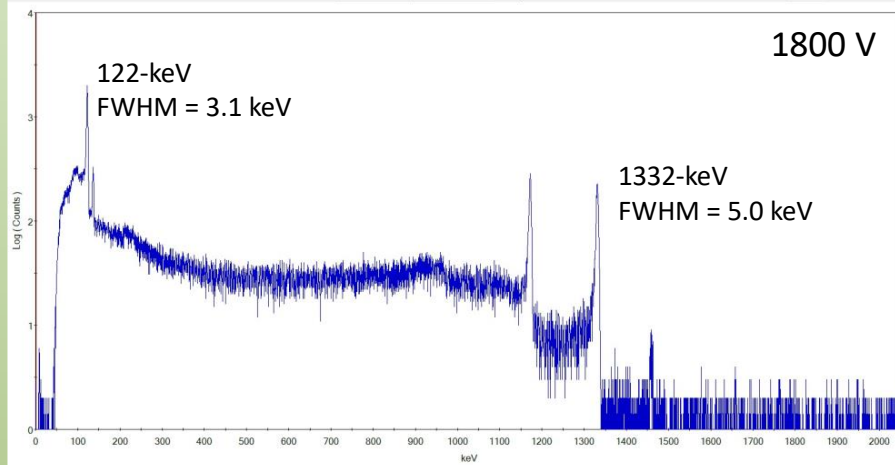
Passivation first, implant second

**Different but still rather
troublesome (surface channel?)**

30% is calculated full efficiency

PHDS Co. HPGe Crystal

Umicore HPGe Crystal



The Umicore HPGe is better. PHDS Co. crystals need to improve to support RCD Detector Geometry.



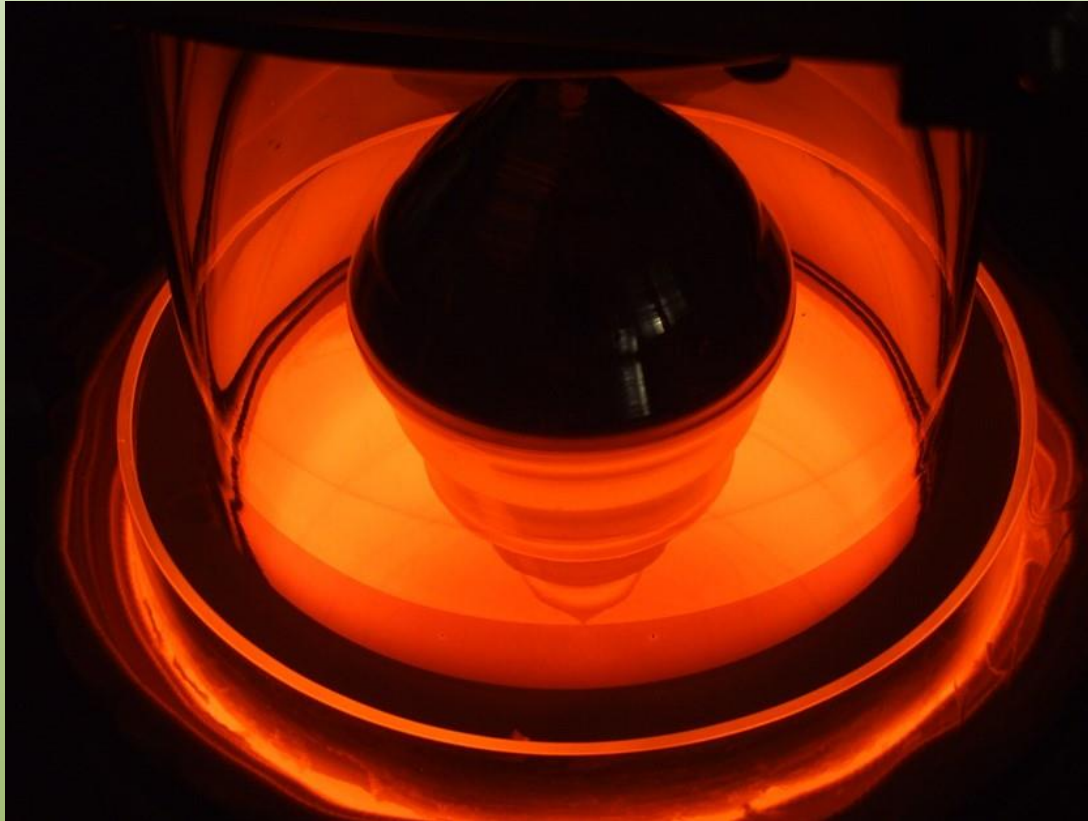
**On to
crystals**

The RCD Detector Geometry can be made to function with reasonable energy resolution

There is a substantial challenge regarding surface channel sensitivity and a resulting loss of live detector volume (similar to last year's result)

2. Crystal Growth — Trying to improve charge collection for RCD detectors

CZ250 Crystal puller



Two major factors:

1. Charge collection
2. Impurities

1. Gas phase phosphorus observations in the attempt to grow RCD Crystals.

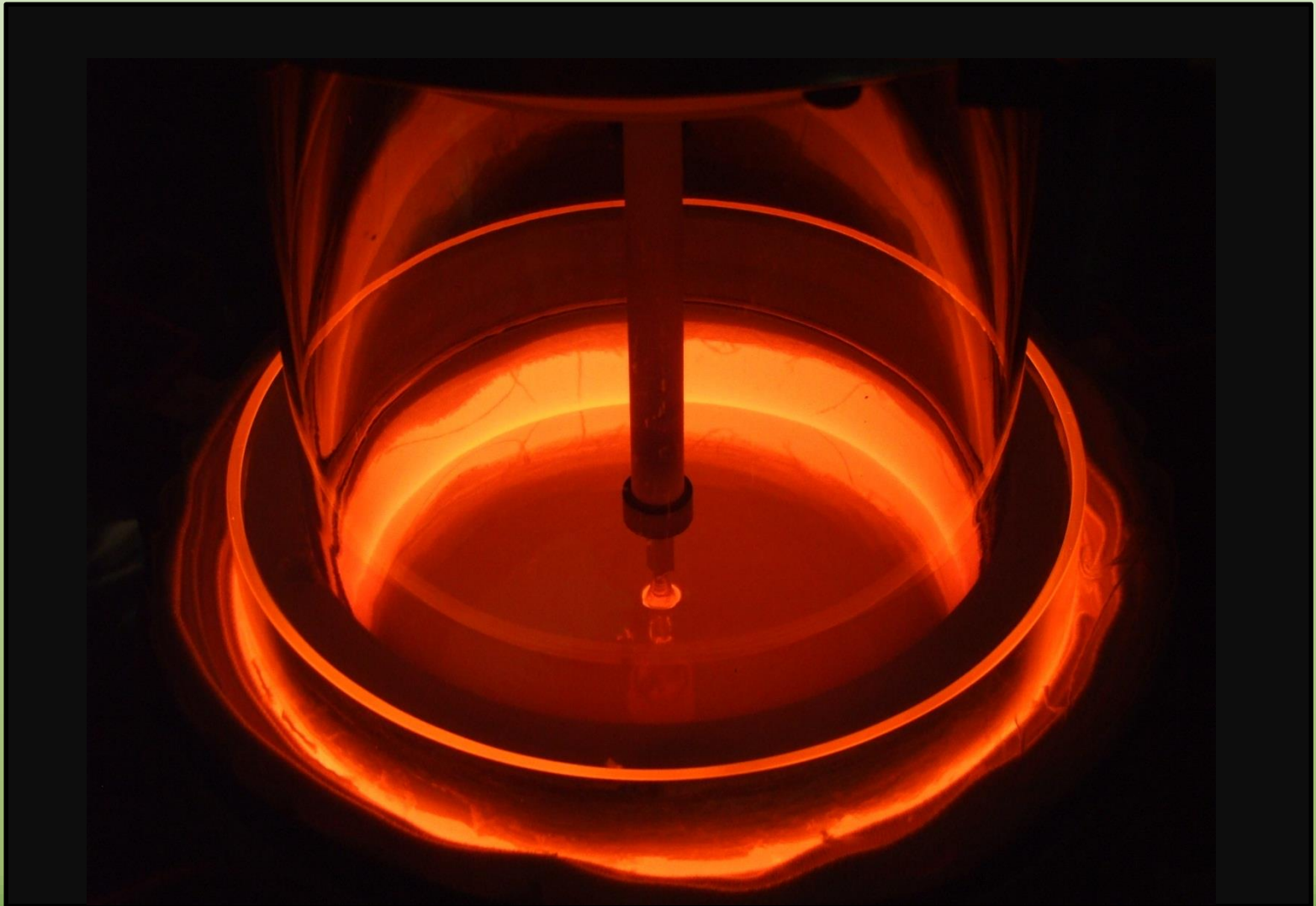
CZ250 Flat bottom quartz crucible

CZ250 Hemispherical quartz crucible

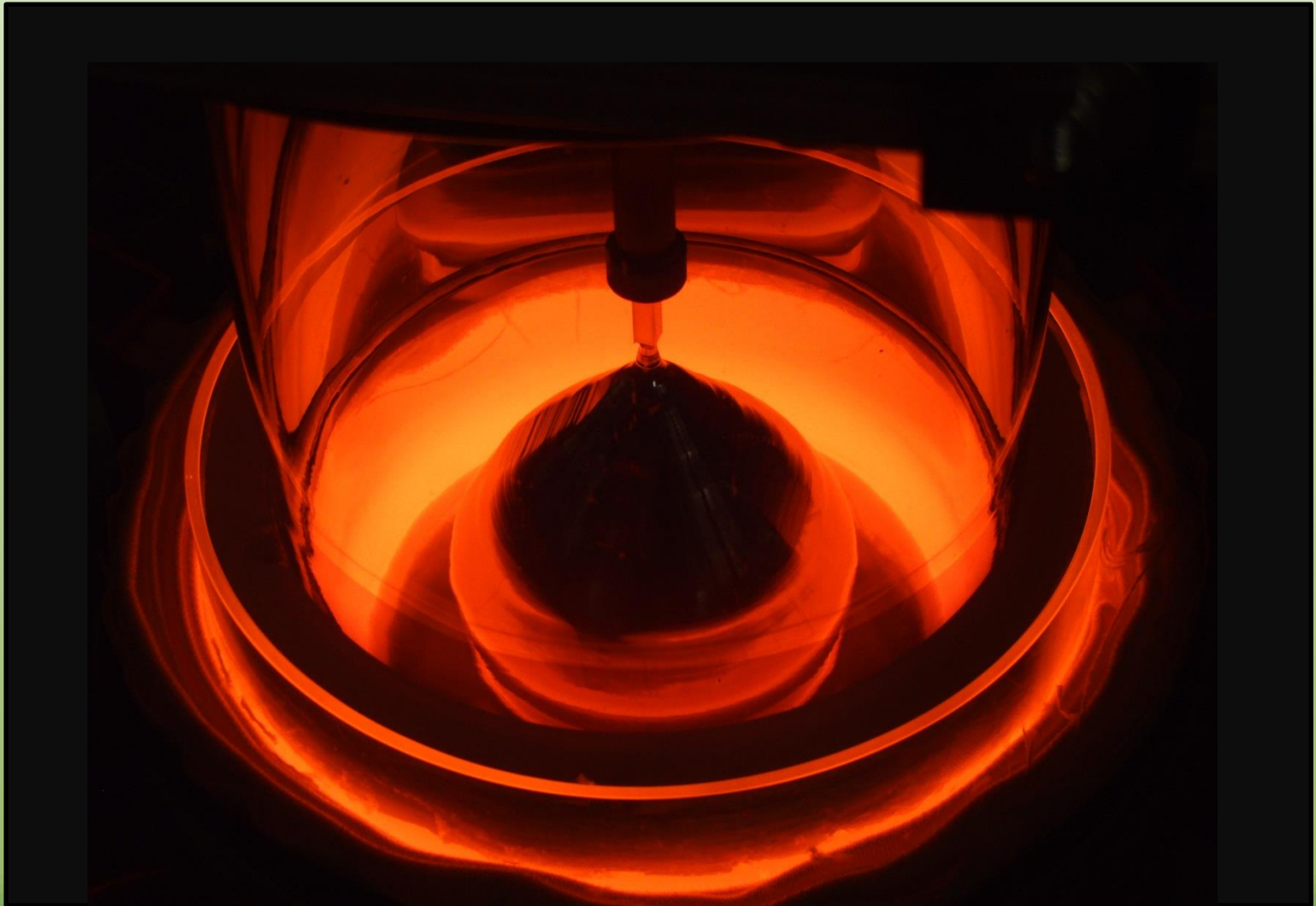
Growth of Crystal



Growth of Crystal



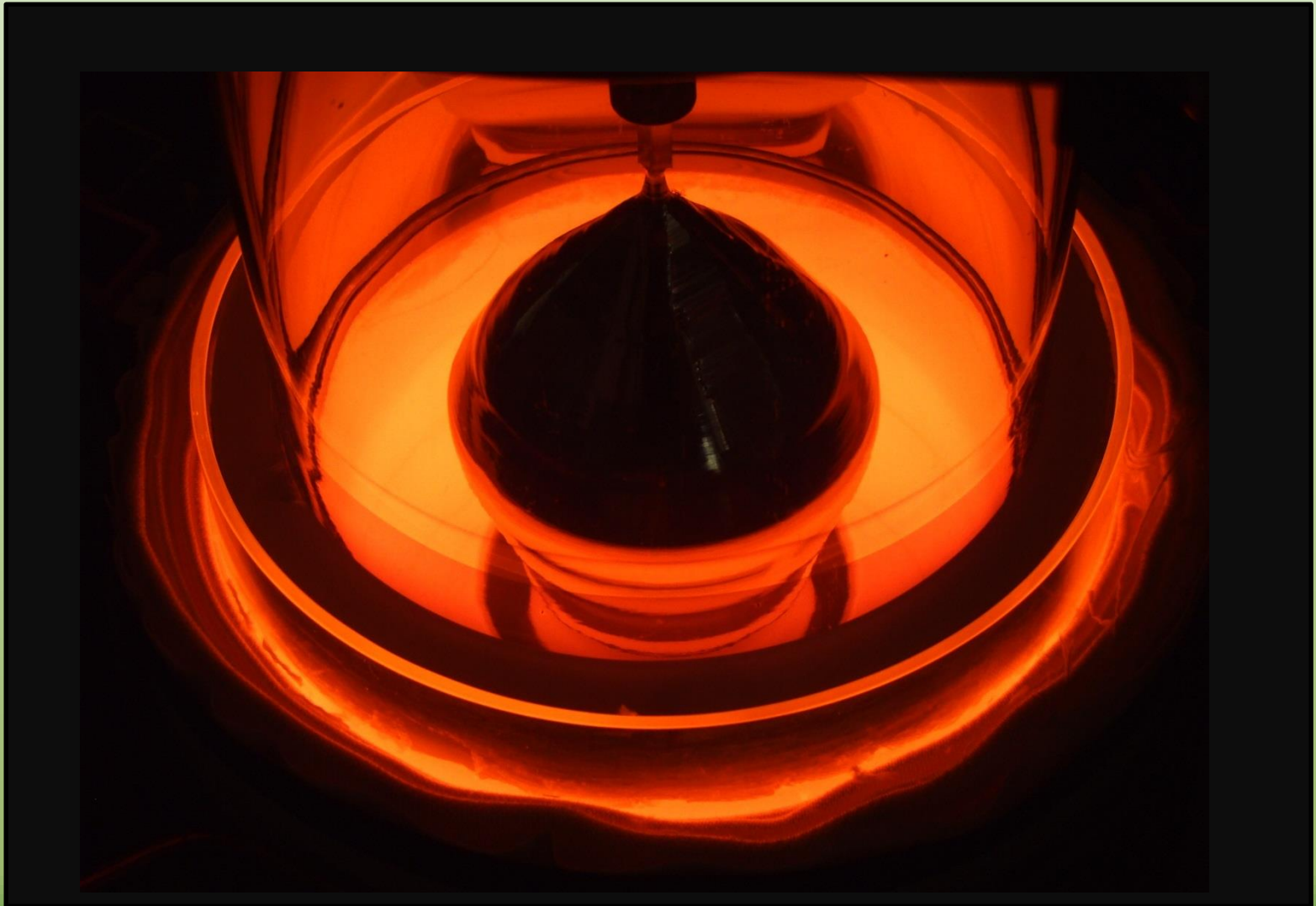
Growth of Crystal



Growth of Crystal

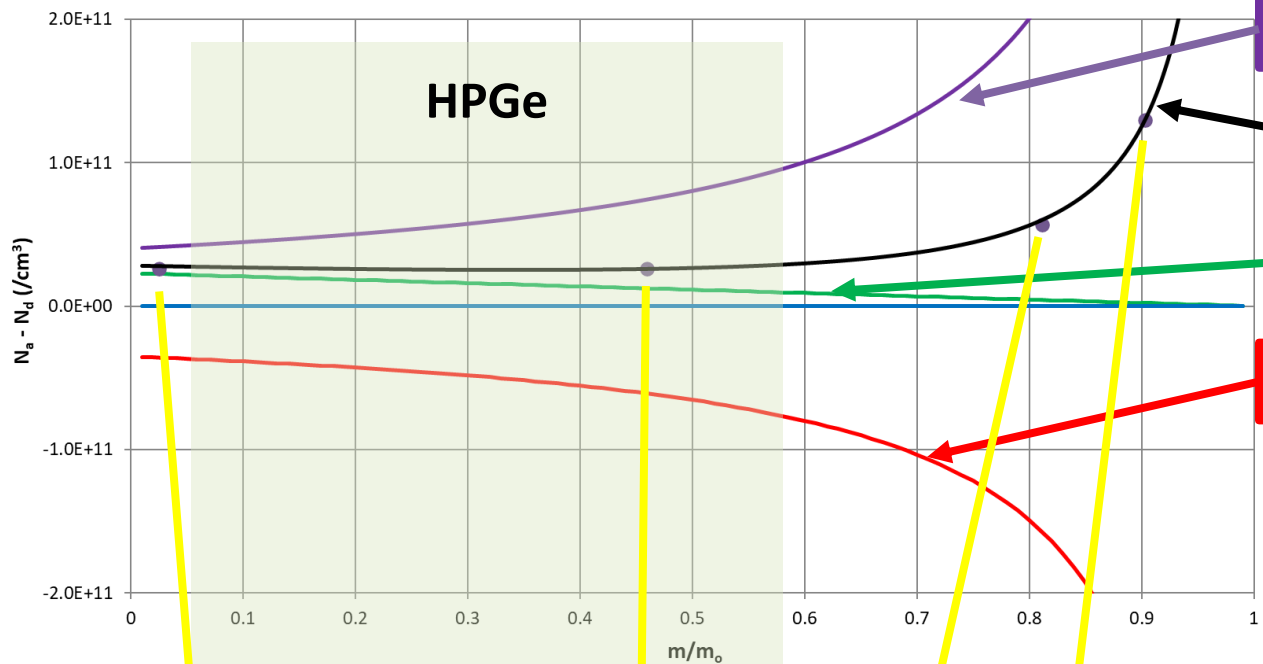


Growth of Crystal



HPGe Crystal





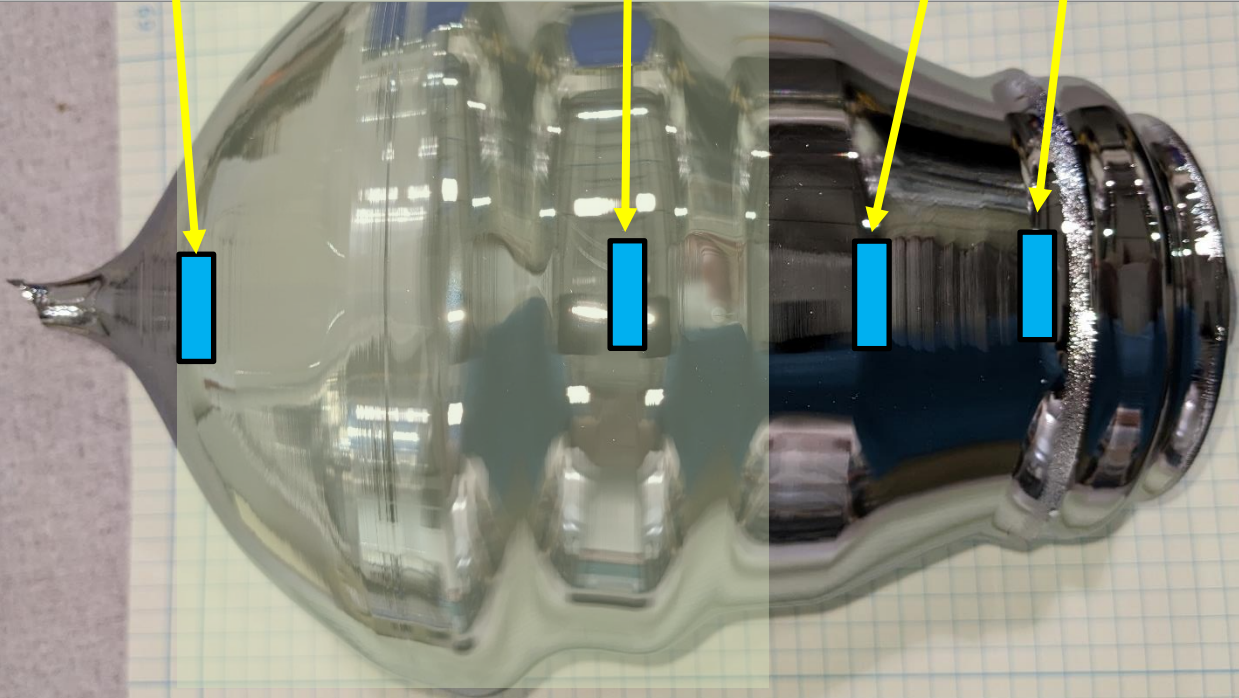
$4.02 \times 10^{13} \text{ /cm}^3$ Indium dope

NET IMPURITY LEVEL

$2.50 \times 10^{10} \text{ /cm}^3$ Aluminum

$3.50 \times 10^{11} \text{ /cm}^3$ Phosphorus

Focus on Phosphorus



- Phosphorus is always present
- Dictates the classic $p \rightarrow n$ character of HPGe
- All HPGe would be n-type due to phosphorus without a p-type dopant
- Phosphorus is the limit to the HPGe axial extent of the HPGe region (RCD)



- **8x Crystals over the past year $2-4 \times 10^{11}$ phosphorus!!**
 - **Best ever!!**
 - **Important for large detectors like RCD and other for low-background counting systems**
- **Vapor phase phosphorus is observable**
- **Allure of successive crystal regrowth**

Thank you