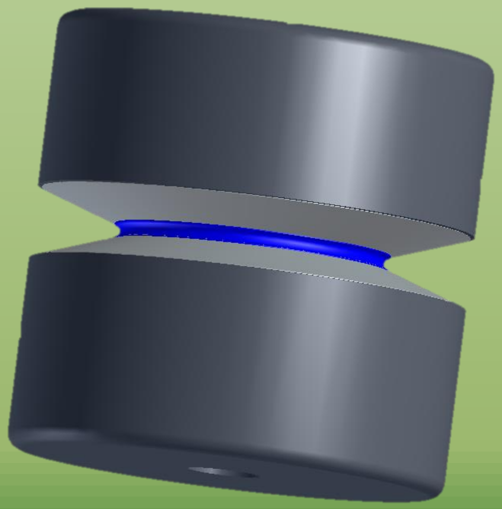
LARGE VOLUME RING-CONTACT HPGE DETECTORS (RCD)

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

PHDS
Gamma Ray Detectors

NP Imager

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

Specialty Operations Products

Versatile Global Commercial Product

Versatile Global Commercial Product

Science Experiment

NPX (150 lbs.)
2008 Laboratory

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

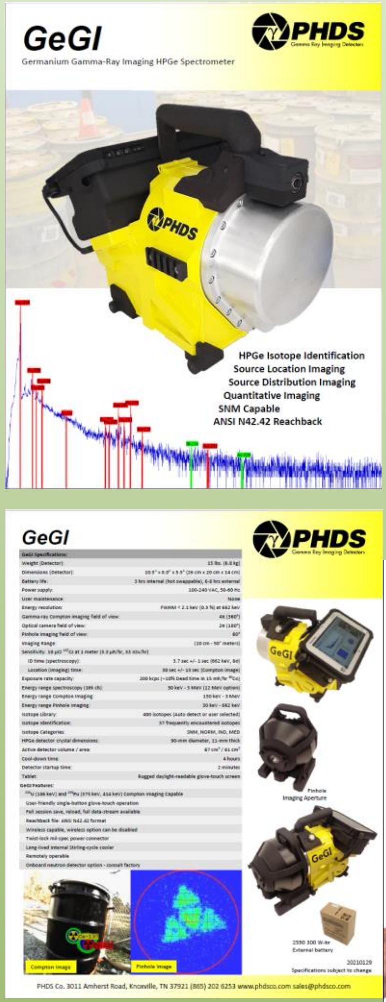
Frontiers **of Nuclear Physics**

Frontlines **of Nuclear Security**

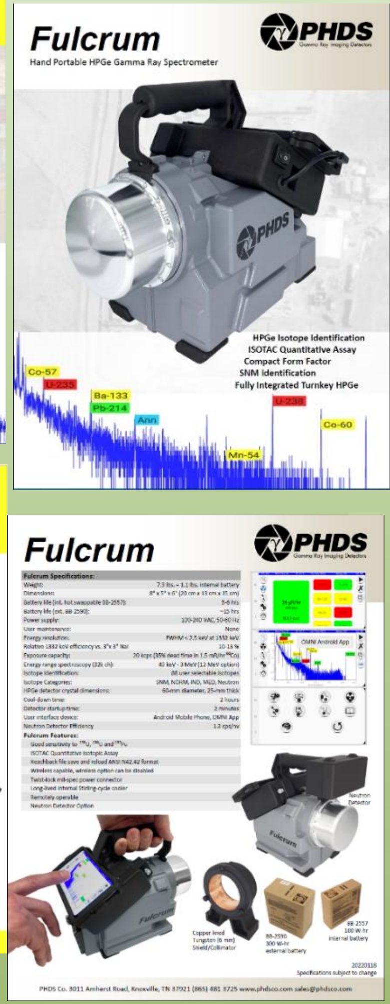
PHDS Co. now manufactures and sells 5 HPGe products

PHDS
Gamma Ray Detectors

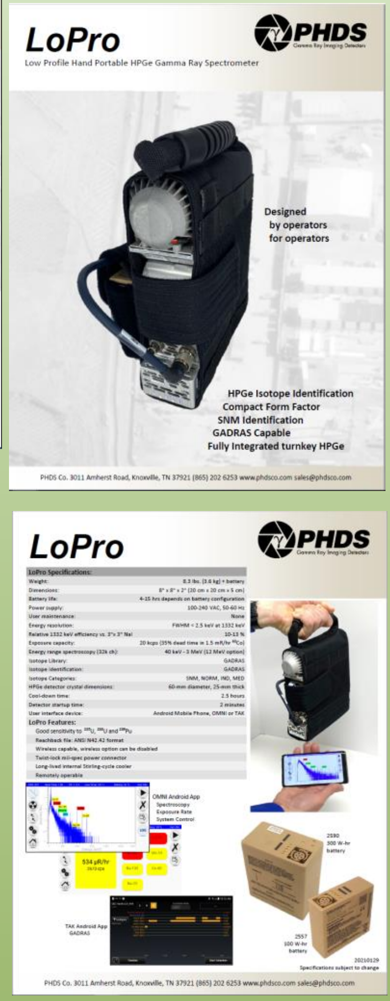
New Fall 2022



Detect, Identify, Locate, Quantify

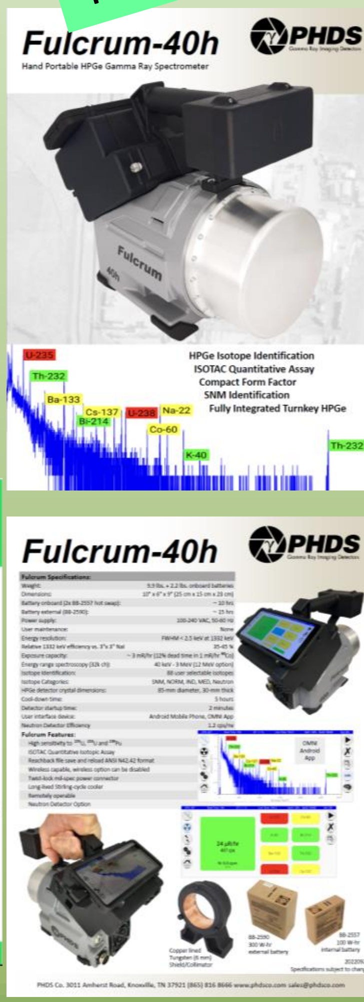


Identify, Quantify, Fast Cool down



Detect, Identify Special Apps

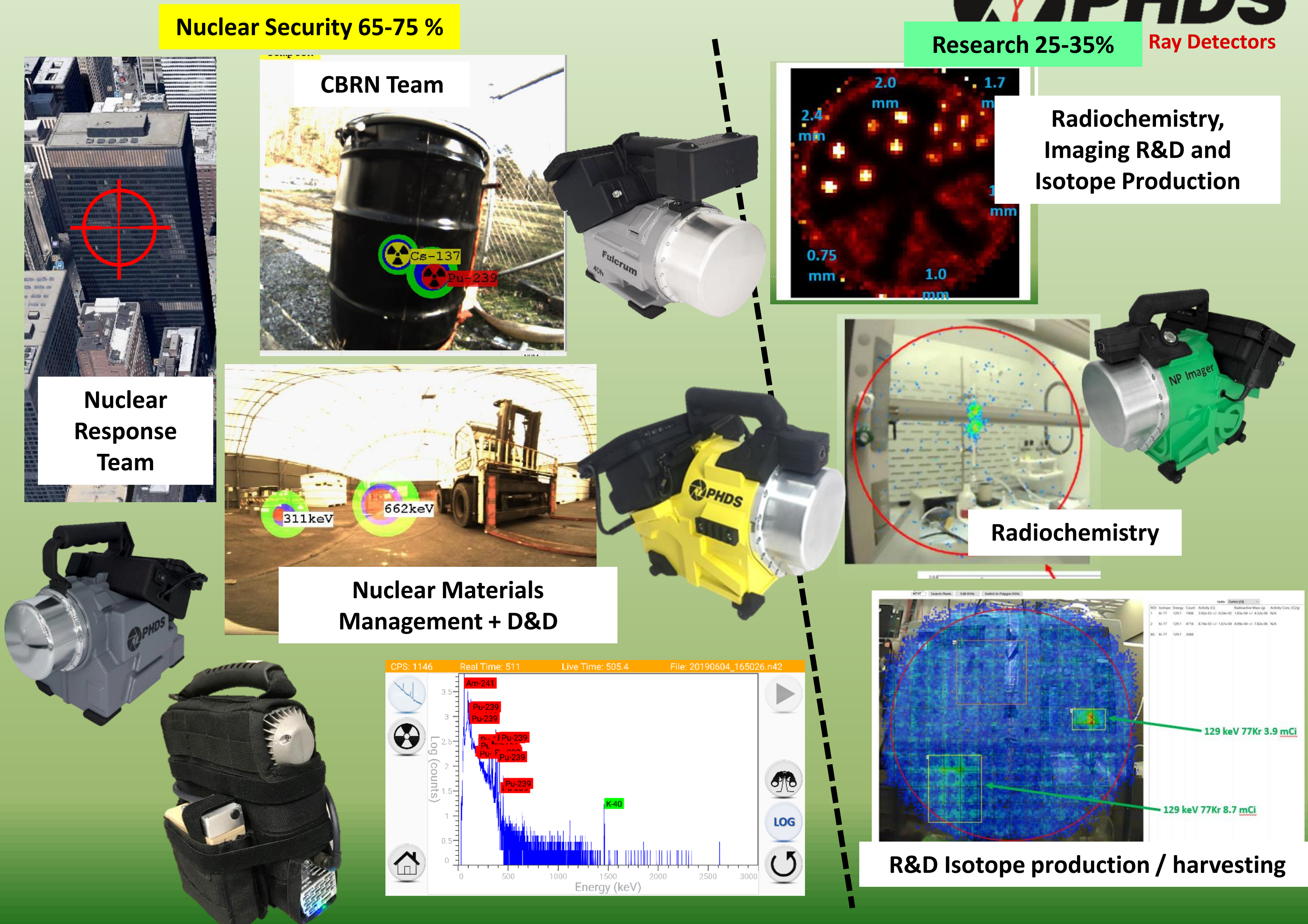
Radiochemistry, Rare Isotopes



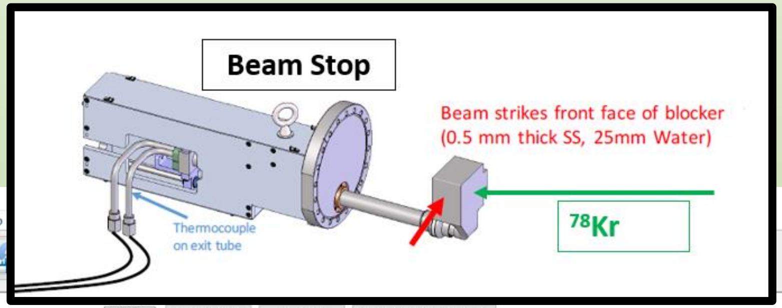
Identify, Quantify, High Sensitivity

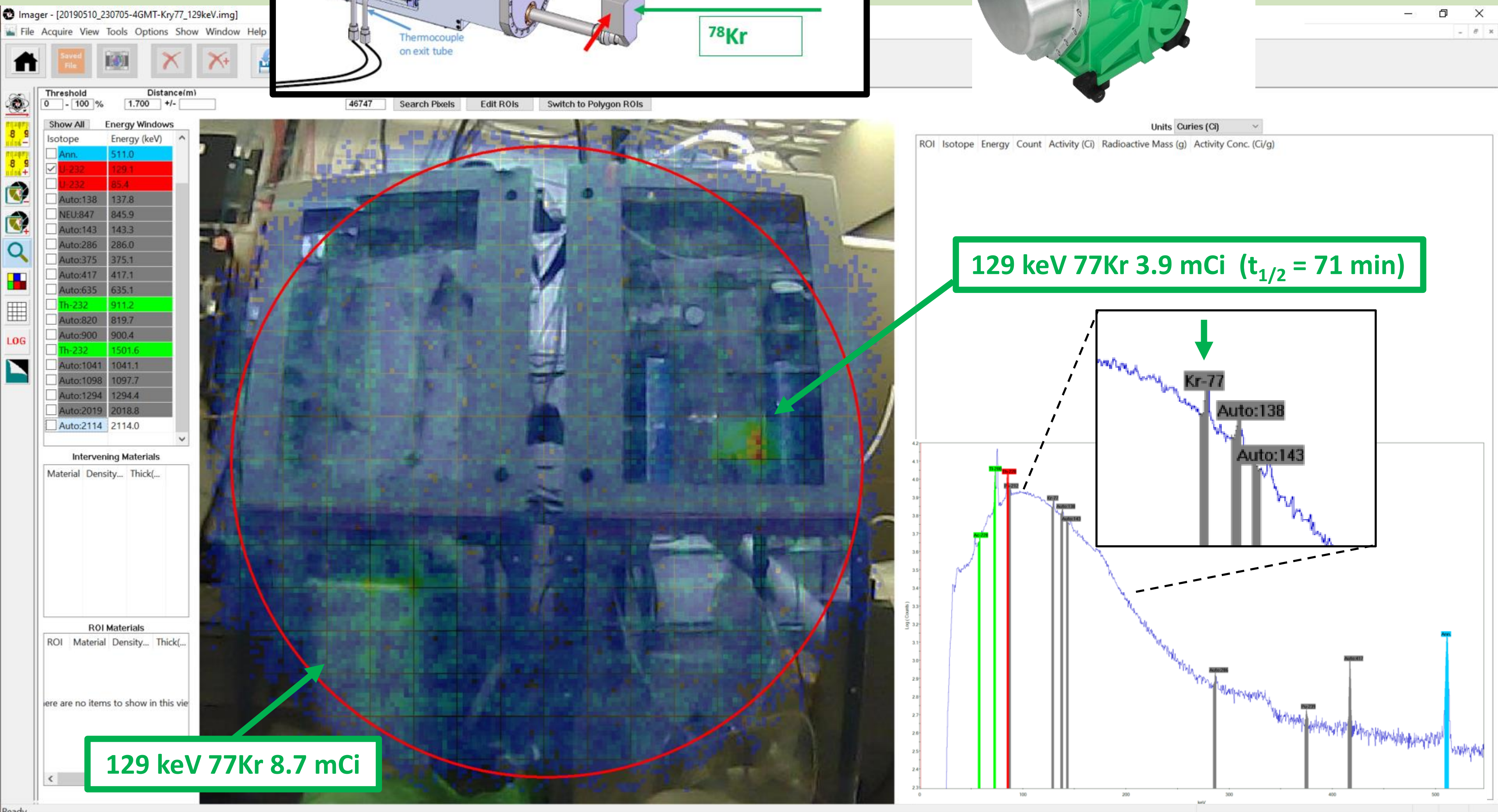
Applications Served by these Products

PHDS
Ray Detectors



NSCL

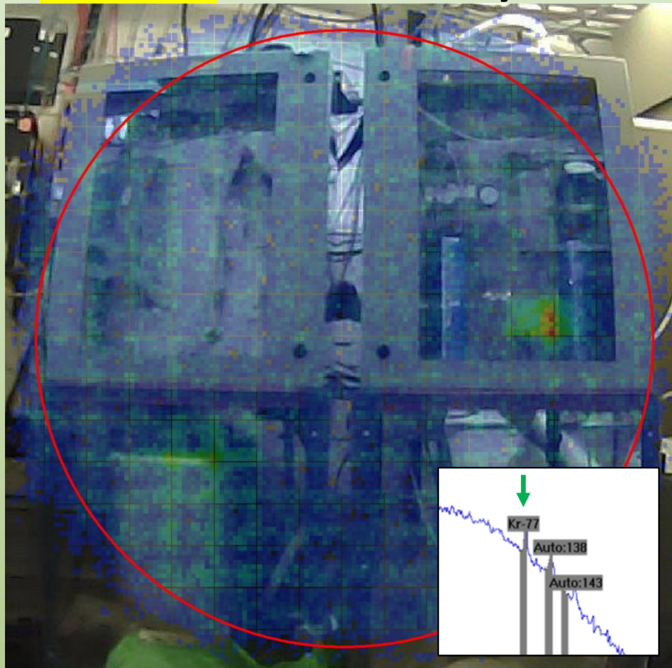




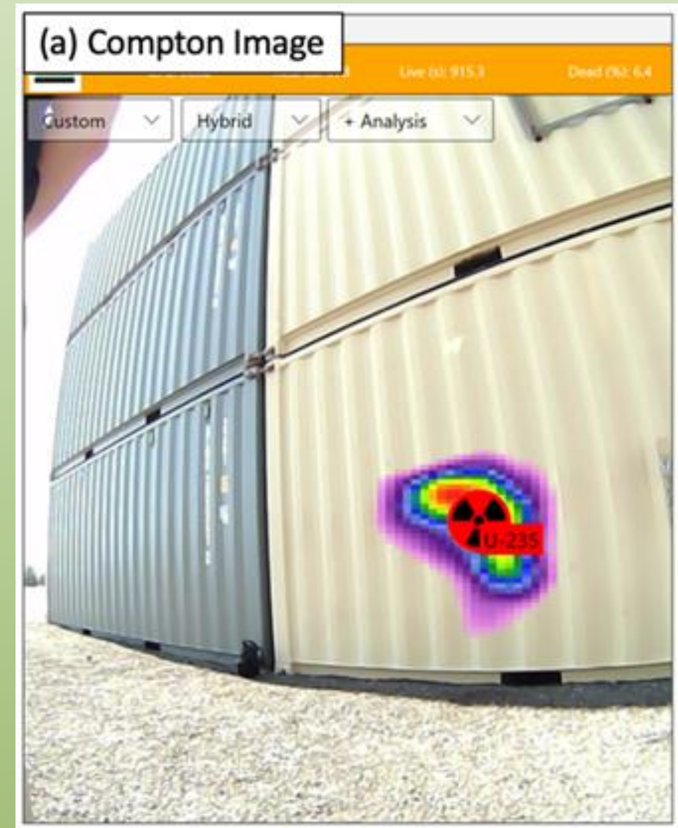
NSCL – NP Imager 2019 Greg Severin

PHDS
Gamma Ray Detectors

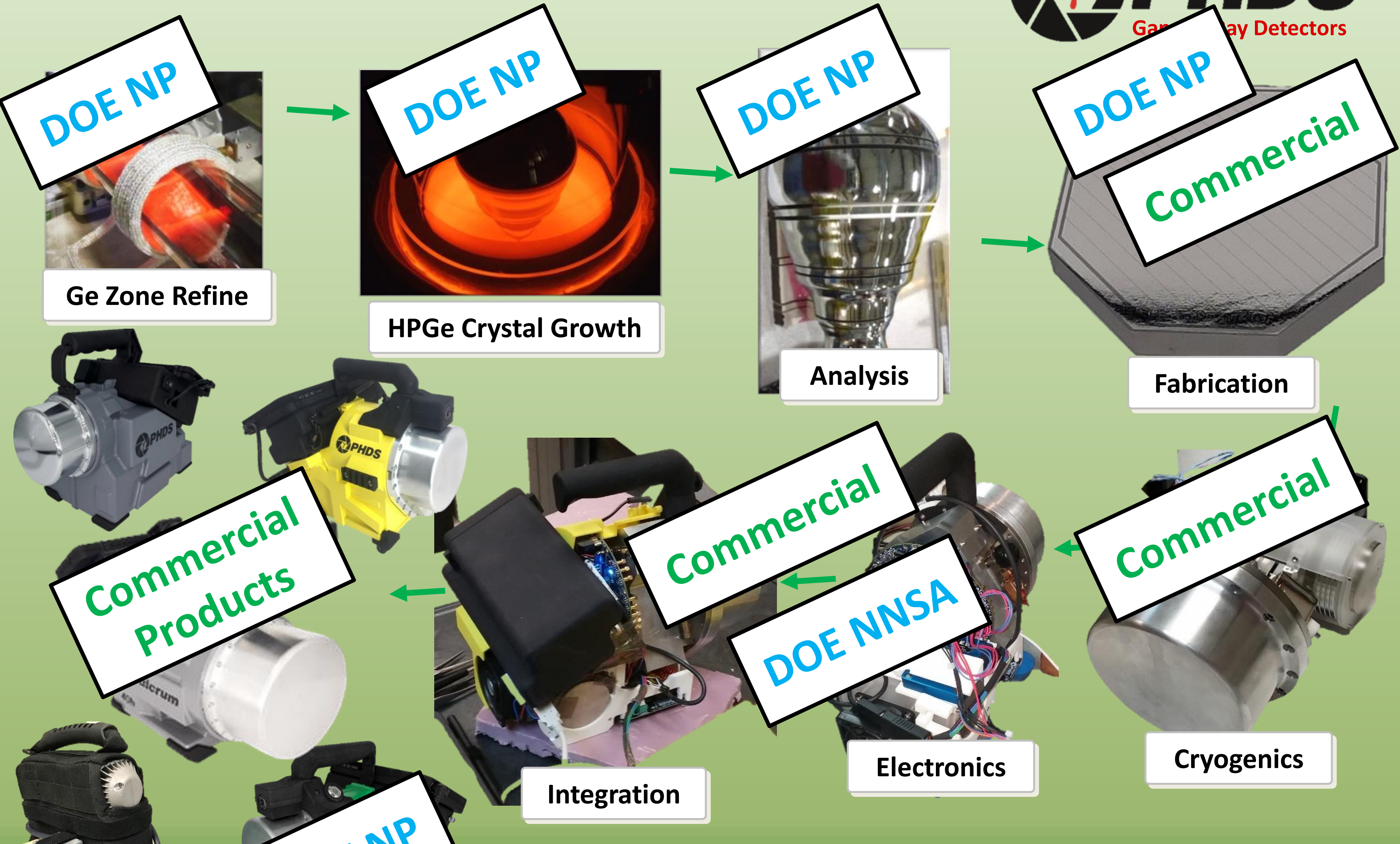
Frontiers of Nuclear Physics



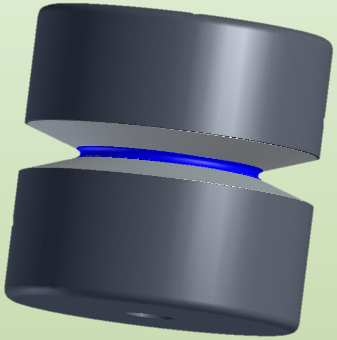
Frontlines of Nuclear Security



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

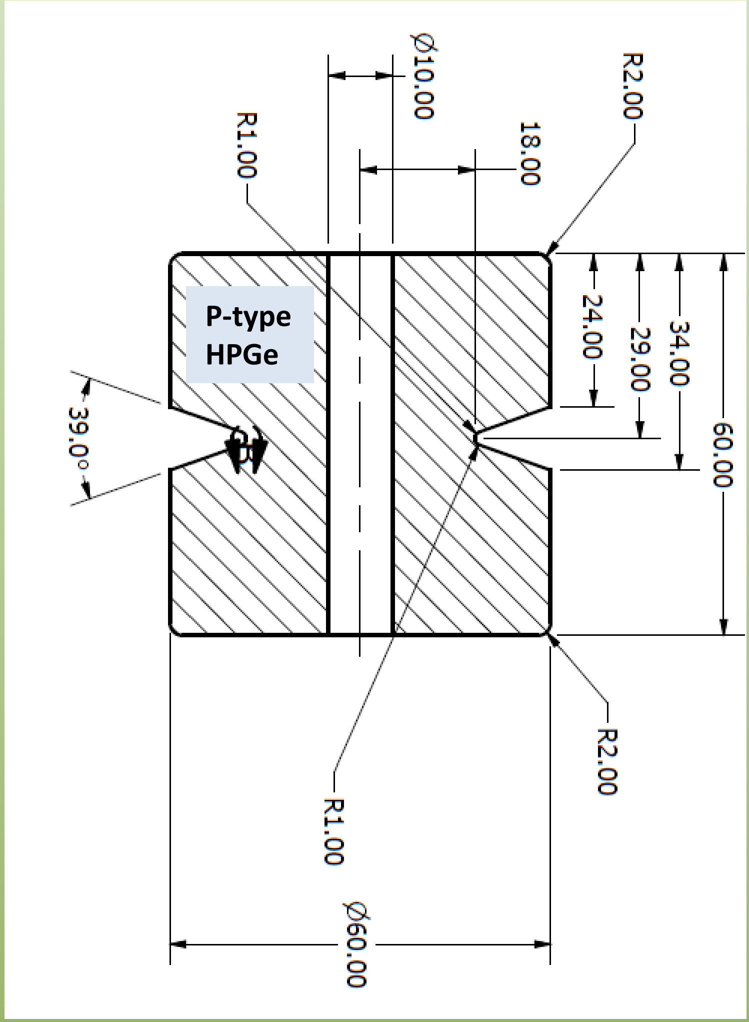
Counting lab feature: Hole can be used as a counting well. The hole diameter can be made larger without affecting detector capacitance (noise).

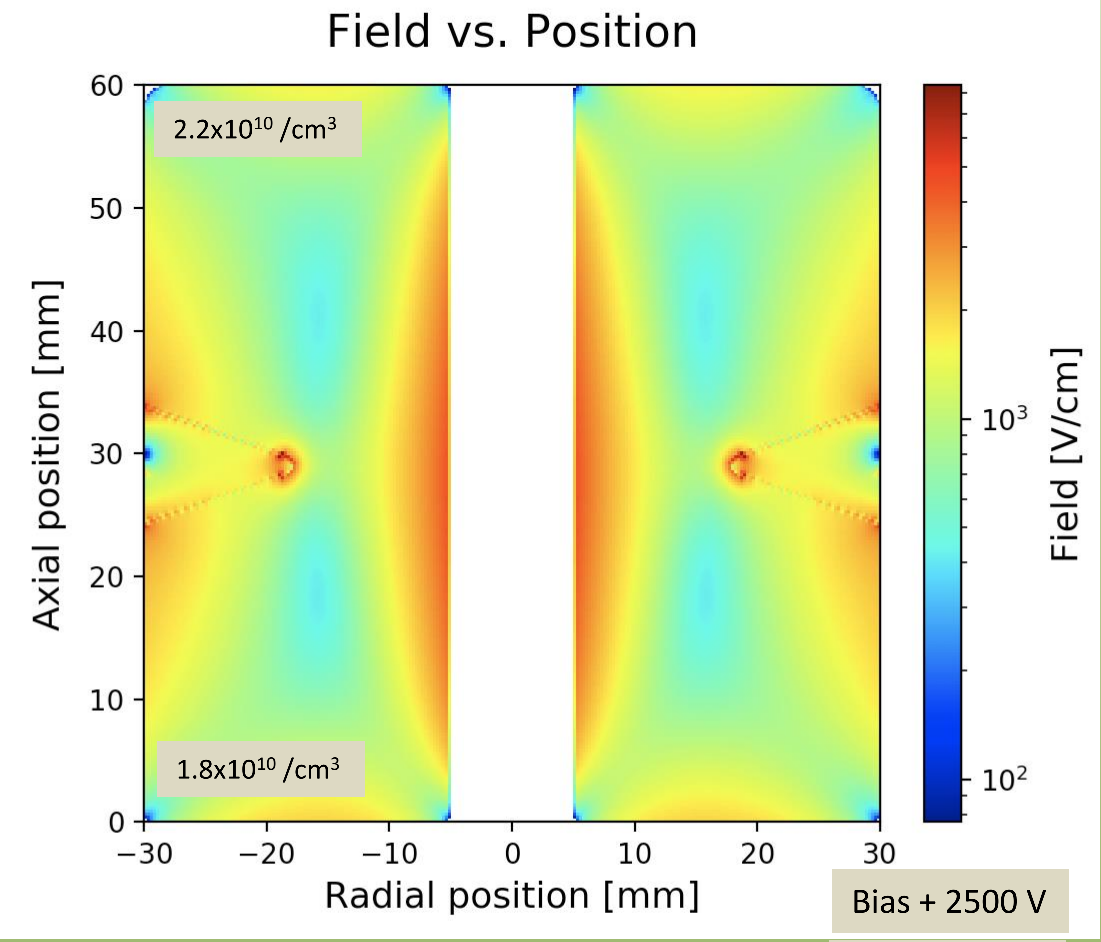
35 mm diameter hole costs only 7-8% of mass

No significant increase in capacitance (noise)

Ring Contact Detector (RCD) Concept – David Radford

PHDS Gamma Ray Detectors



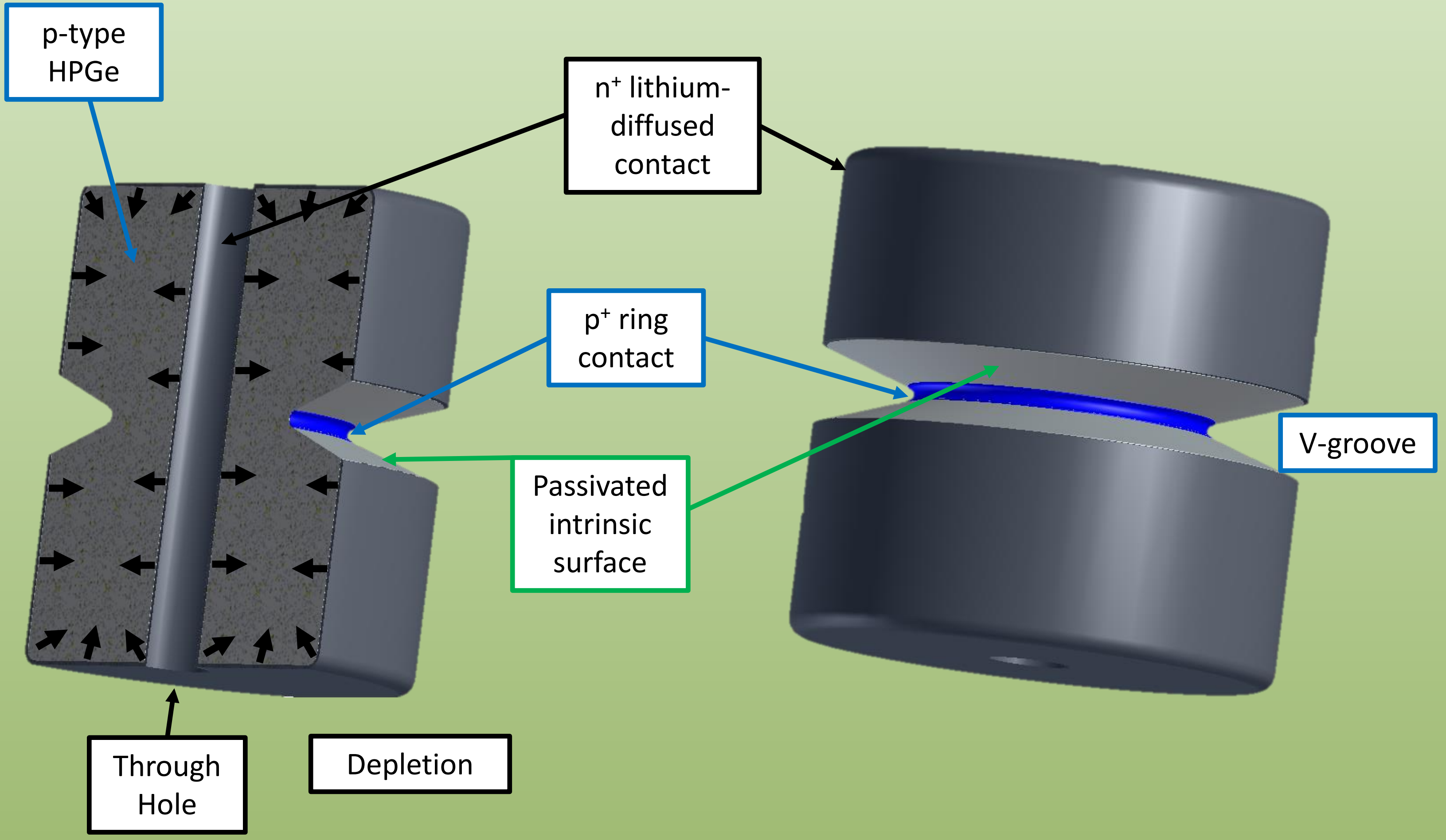


Bias + 2500 V

V_{depl} = + 1600 V

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

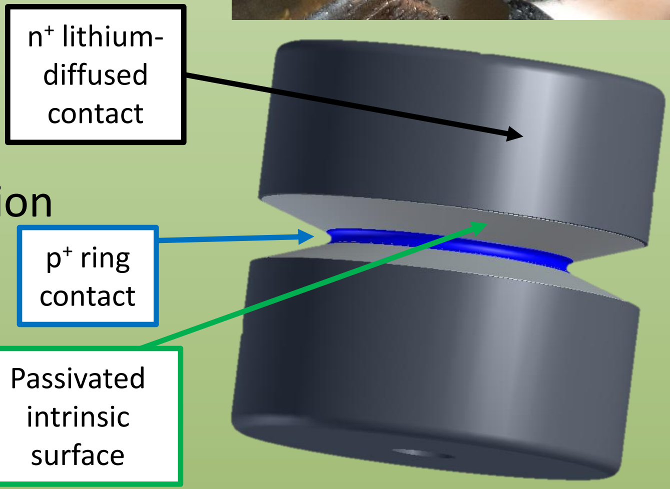
Ring Contact Detector (RCD)
Concept – David Radford

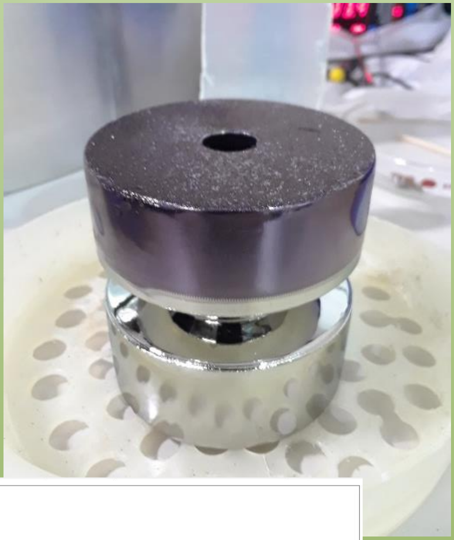


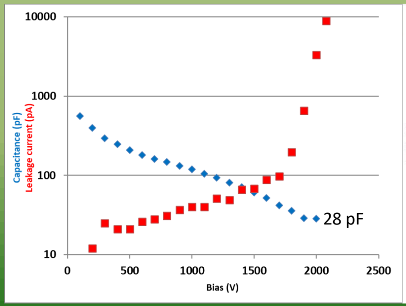
RCD Phase II Experimental Plan – 3 parts
Develop the 3 key enablers to demonstrate RCD

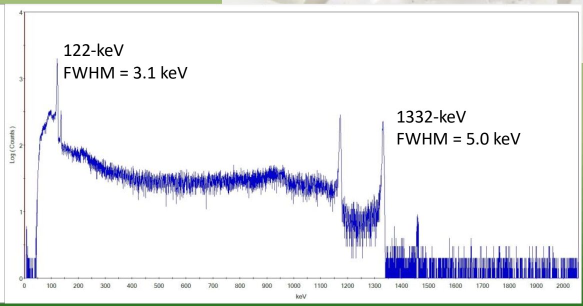
PHDS Gamma Ray Detectors

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

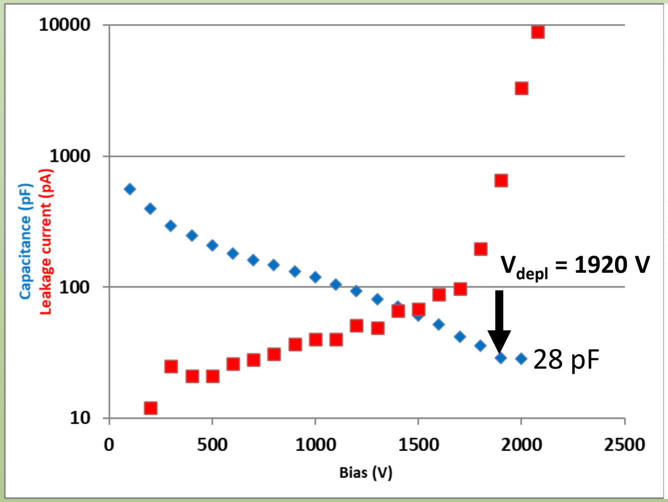


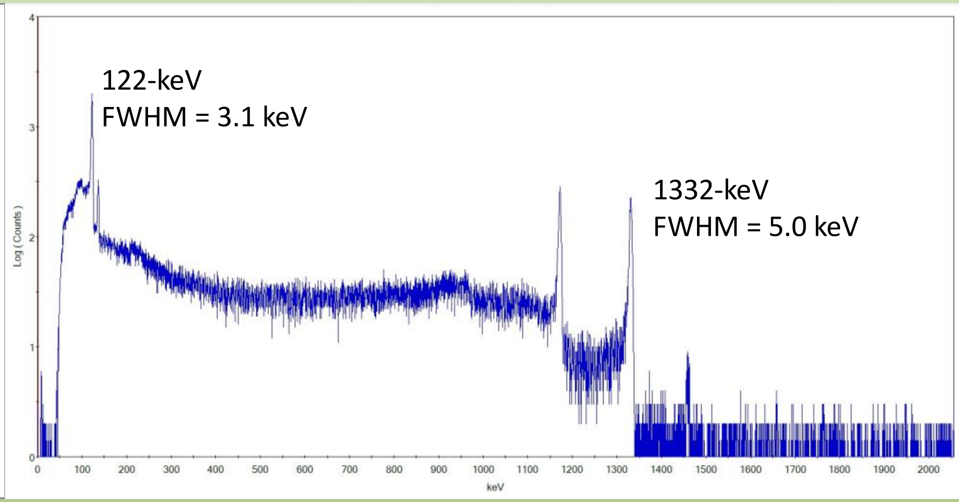






2. Semiconductor Detector Processing
RCD detector testing and again.

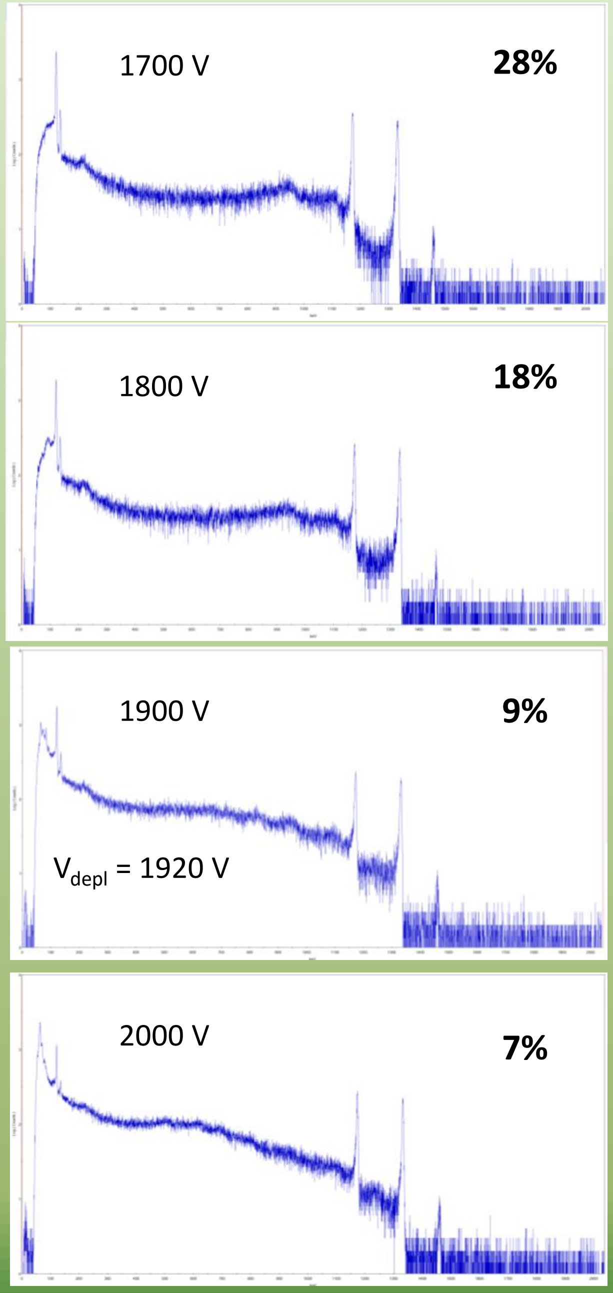


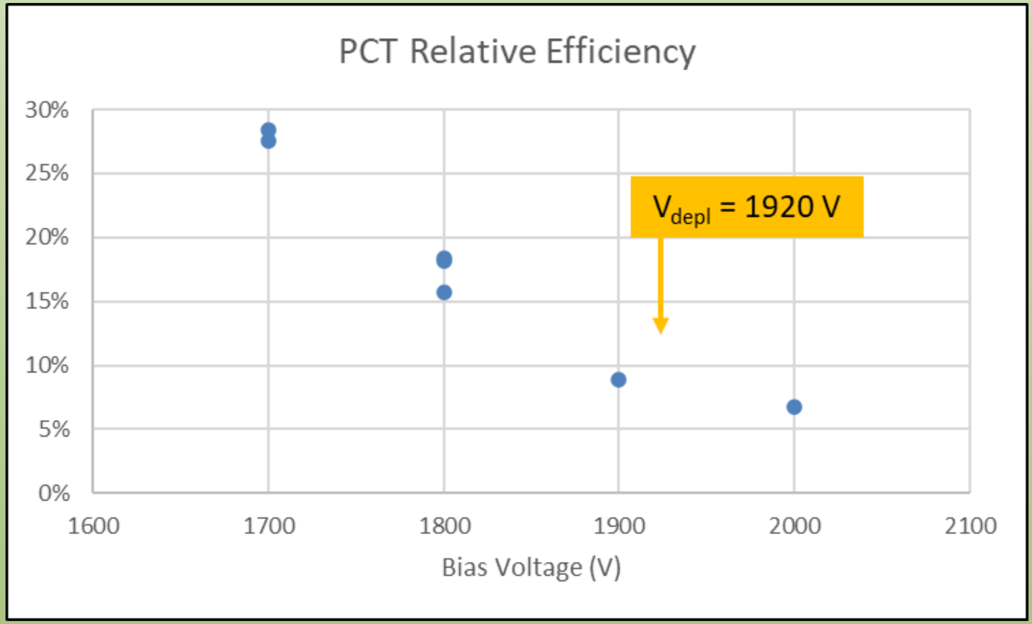


Progress points

- **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

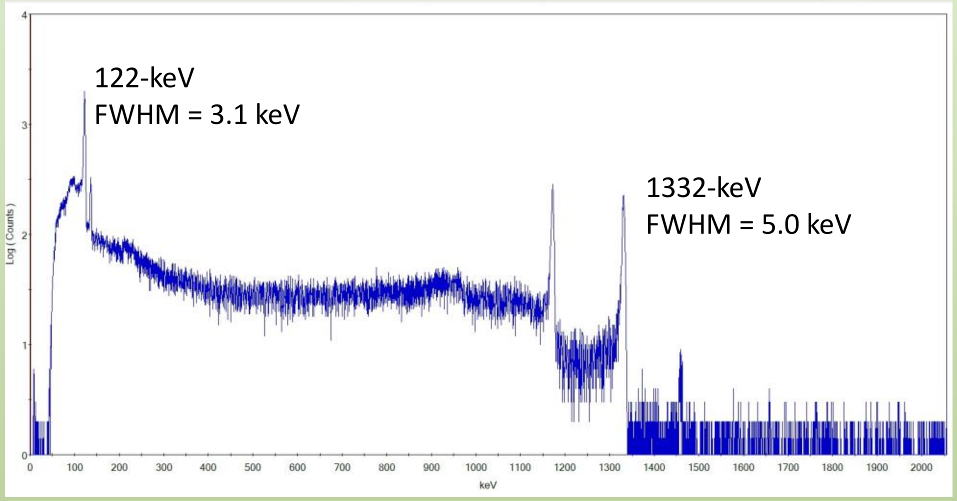




The full-energy 1332-keV peak efficiency decreases dramatically with increasing bias near V_{depl} – an interesting result (implant first, passivation second)

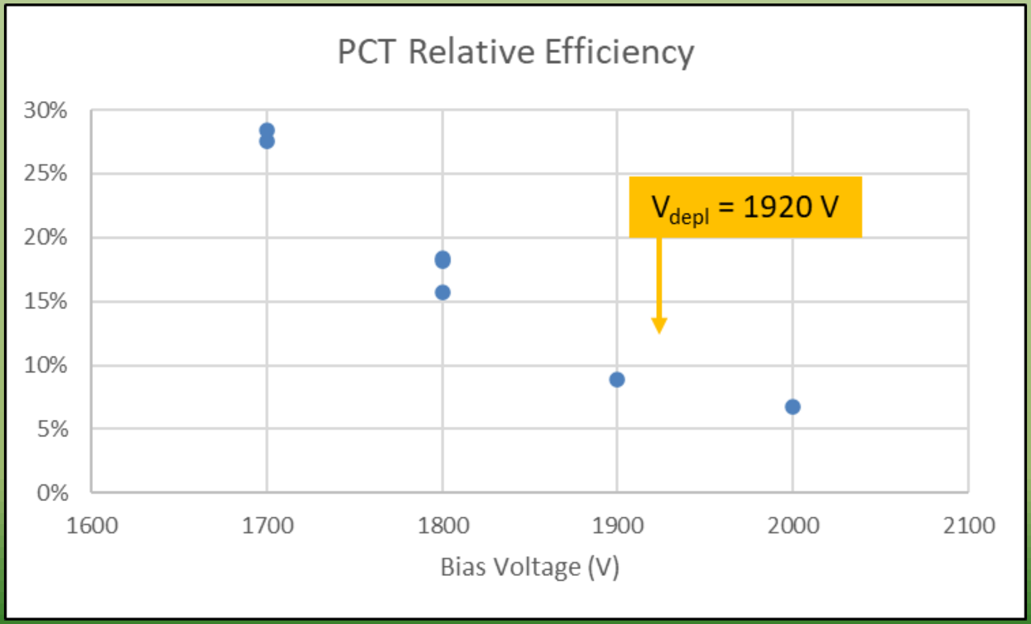
PHDS Gamma Ray Detectors

Spectroscopy



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

Loss of efficiency



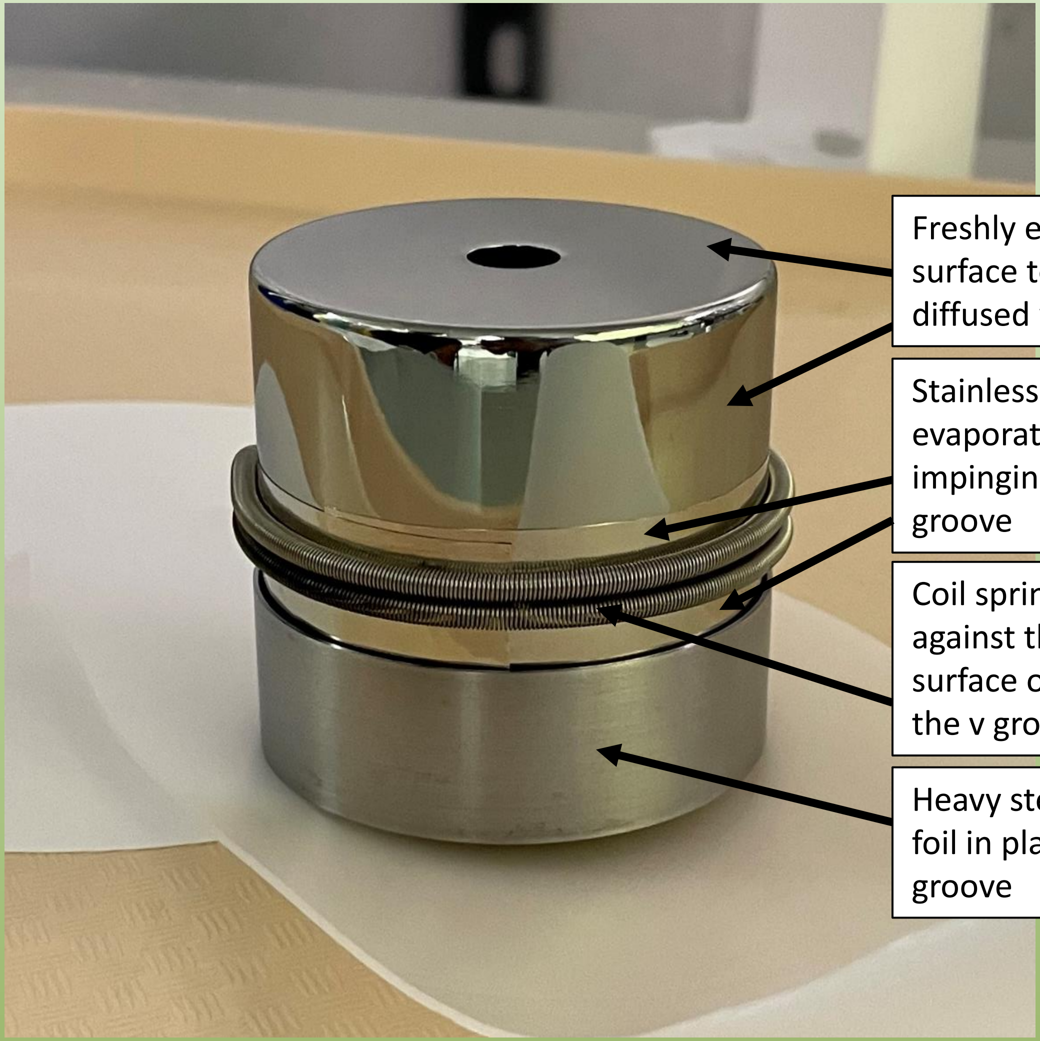
- Change the order of operations in the fabrication to affect the loss of efficiency
  - Implant first, passivation second
  - Passivation first, implant second

Umicore 3000116784-000001 Crystal Made into an RCD

PHDS
Gamma Ray Detectors

Umicore 3000116784-000001 Crystal Made into an RCD – Lithiation

PHDS
Gamma Ray Detectors



Freshly etched germanium surface to be thermally diffused with lithium

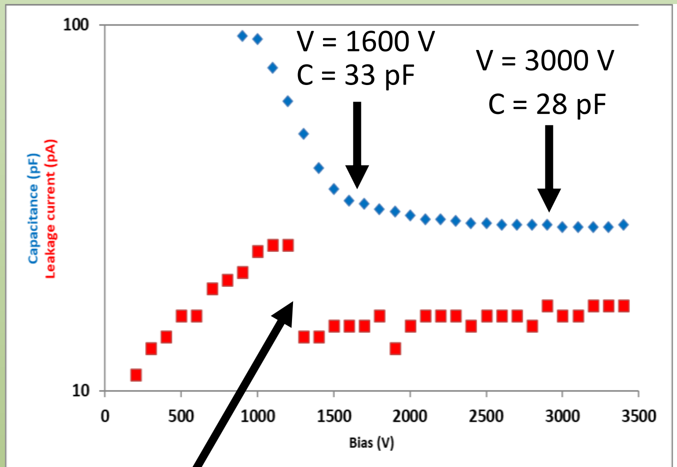
Stainless steel foil to block evaporated lithium from impinging on the intrinsic v-groove

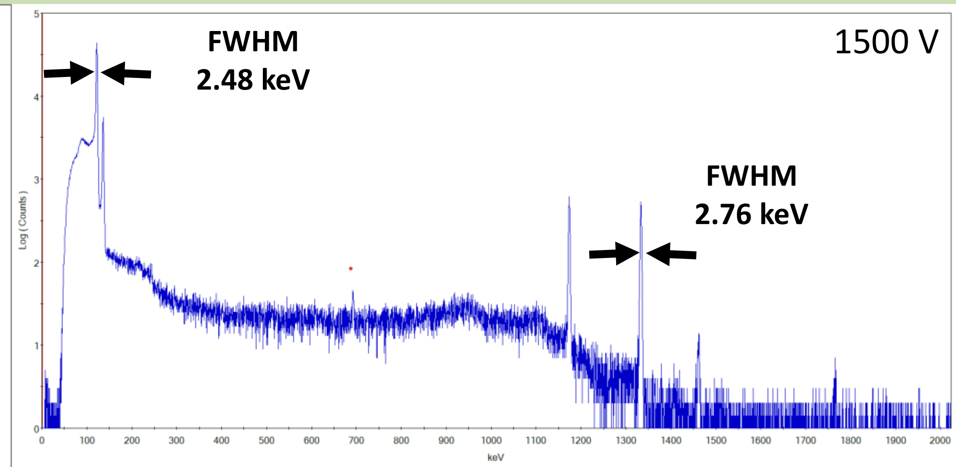
Coil spring to hold foil tightly against the cylindrical surface of the detector over the v groove

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

Umicore 3000116784-000001 Crystal
Made into an RCD

PHDS
Gamma Ray Detectors





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

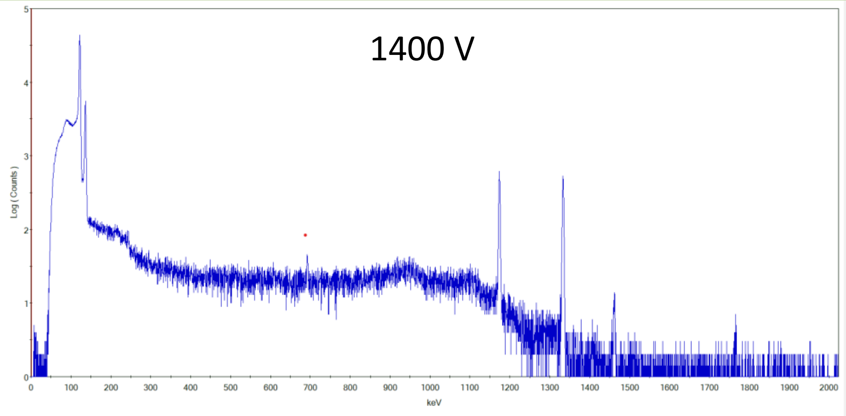
This is not so normal. !!??

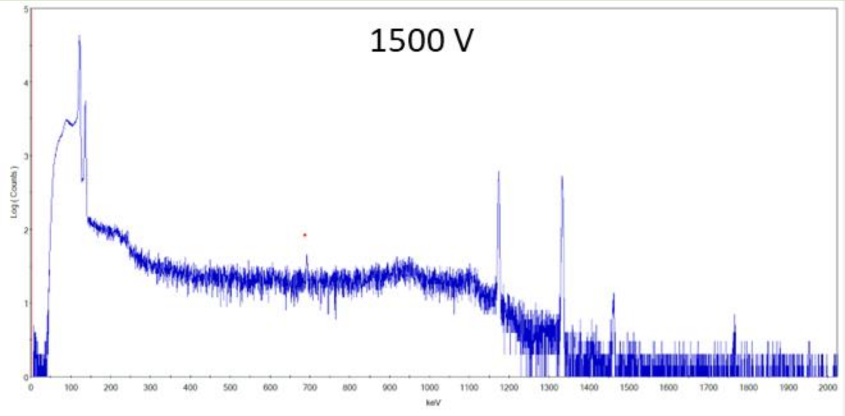
IR leakage pinching off from the ring contact

Spectroscopy shown at 1500 V

Umicore 3000116784-000001 Crystal
Made into an RCD

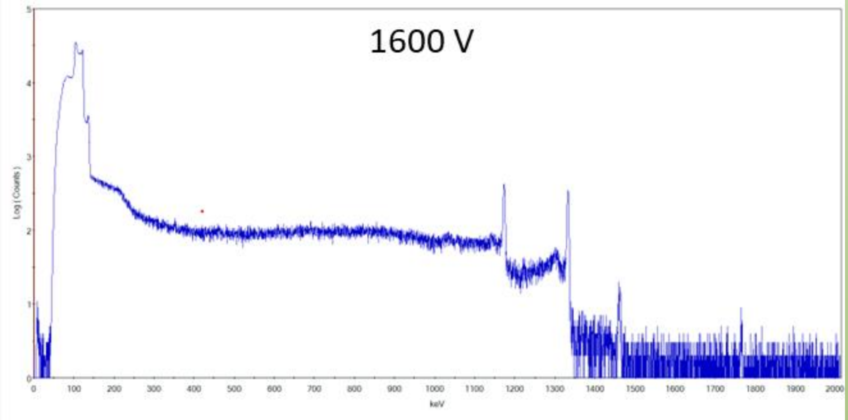
PHDS
Gamma Ray Detectors



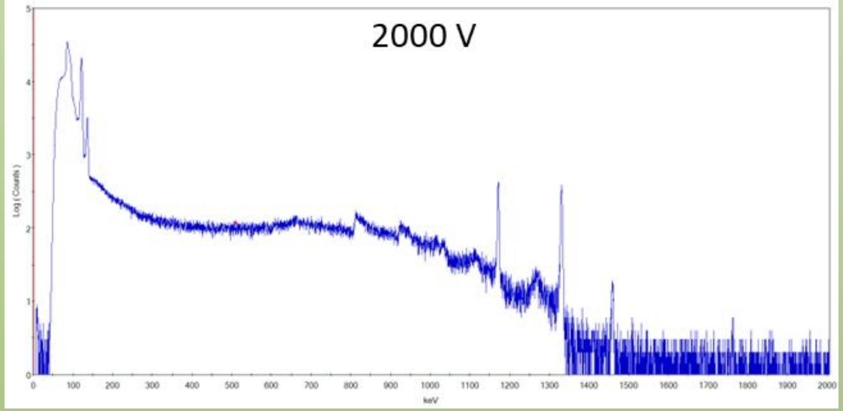


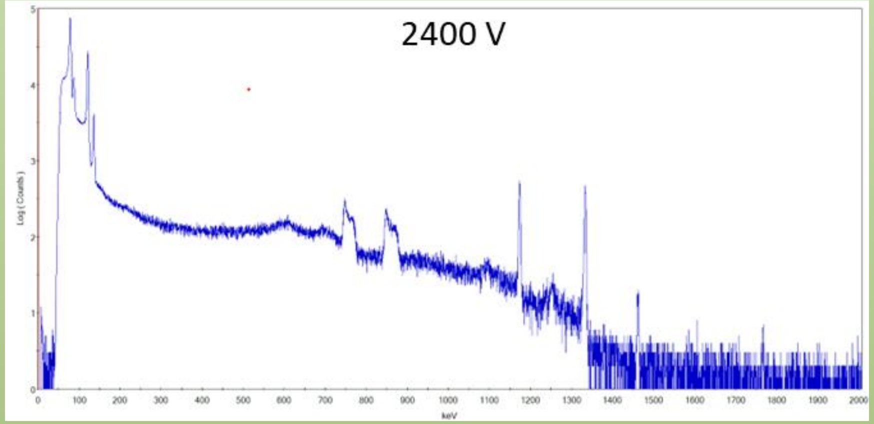
Gamma Ray Detectors

Vdepl = 1600 V



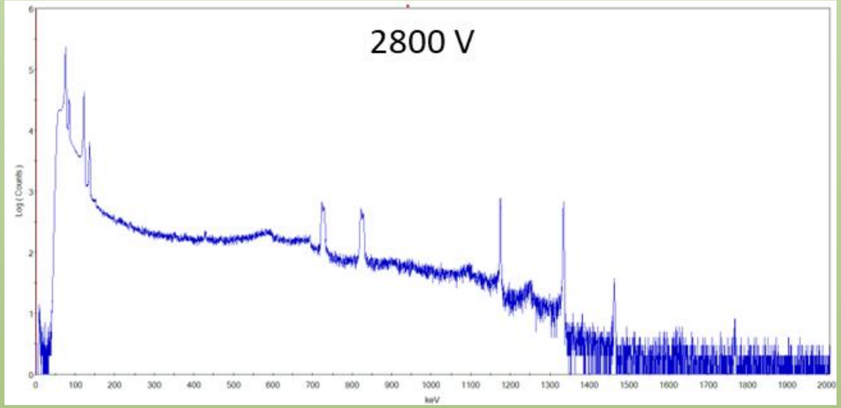
PHDS
Gamma Ray Detectors

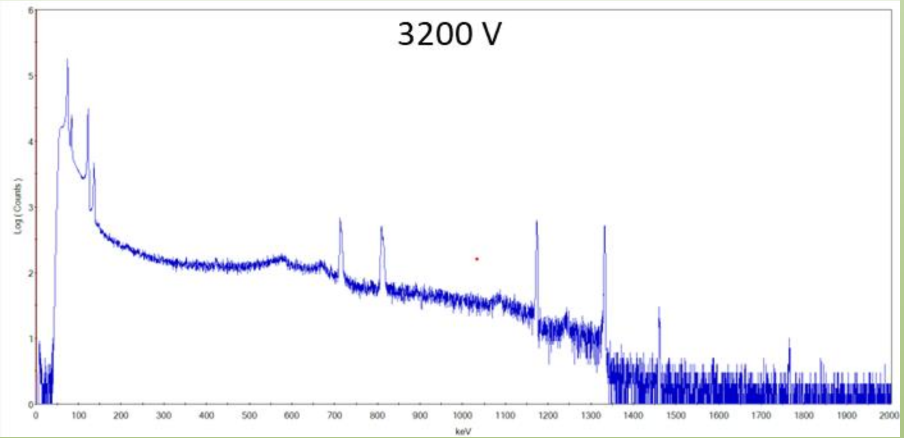


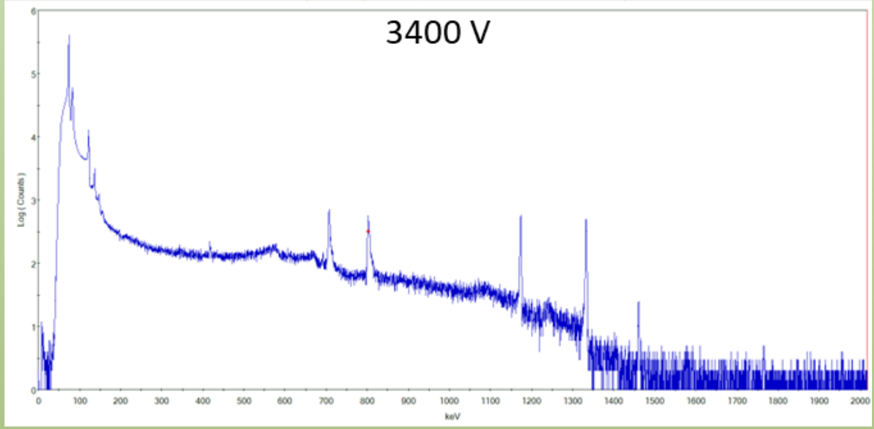


2400 V
Log (Counts)
keV

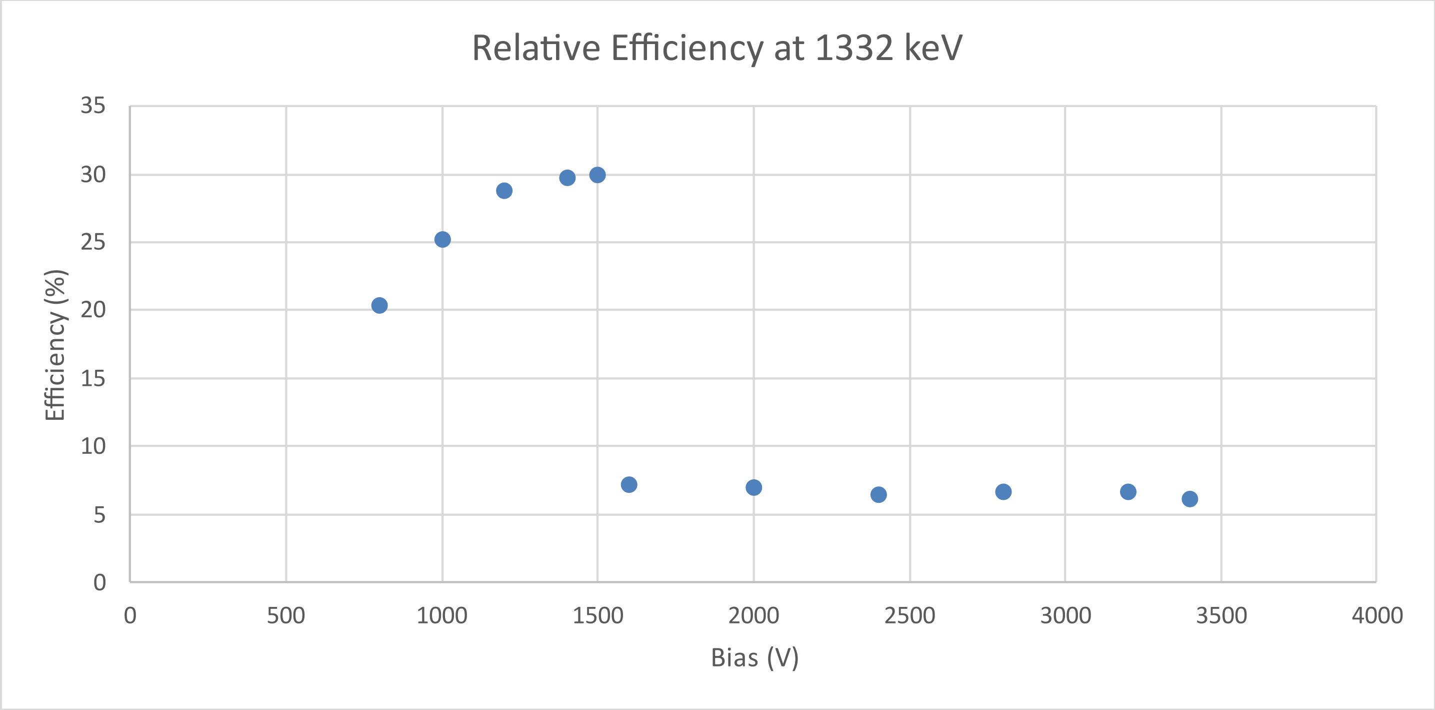
PHDS
Gamma Ray Detectors




3200 V
Log (Counts)
keV
0
1
2
3
4
5
6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000


3400 V
Log (Counts)
0
1
2
3
4
5
6
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
keV

Loss of efficiency



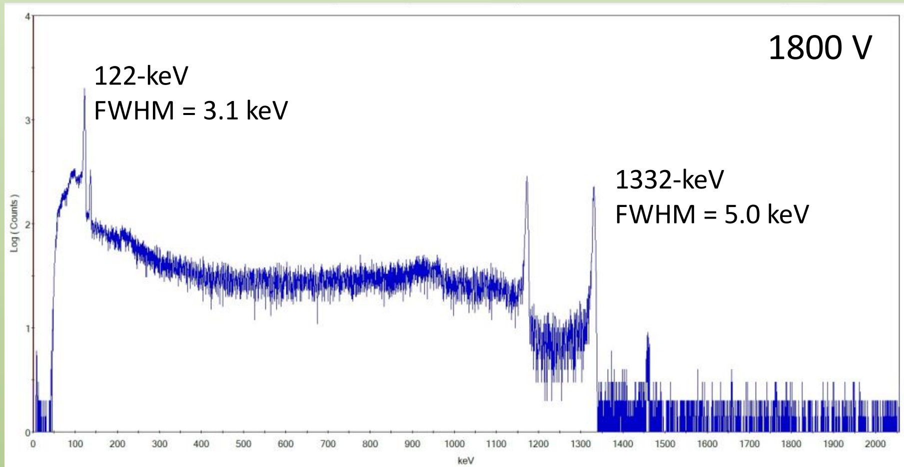
Passivation first, implant second

Different but still rather troublesome (surface channel?)

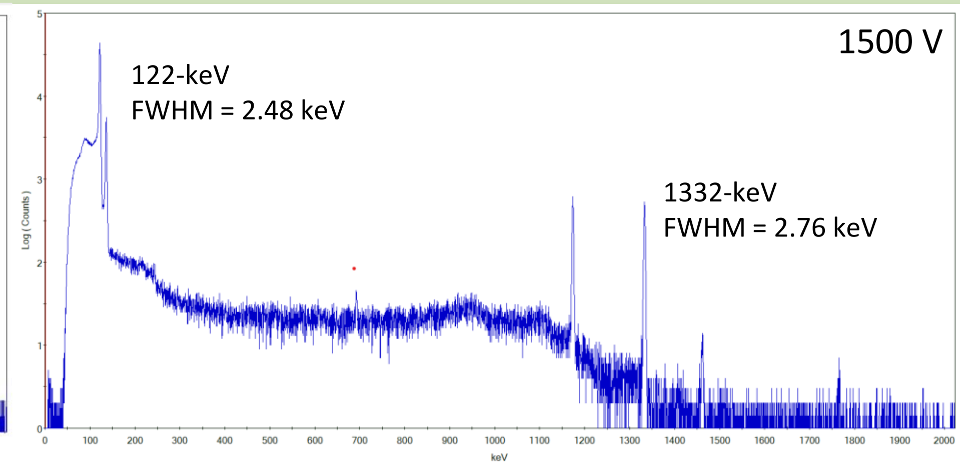
30% is calculated full efficiency

Spectroscopy

PHDS Co. HPGe Crystal



Umicore HPGe Crystal



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

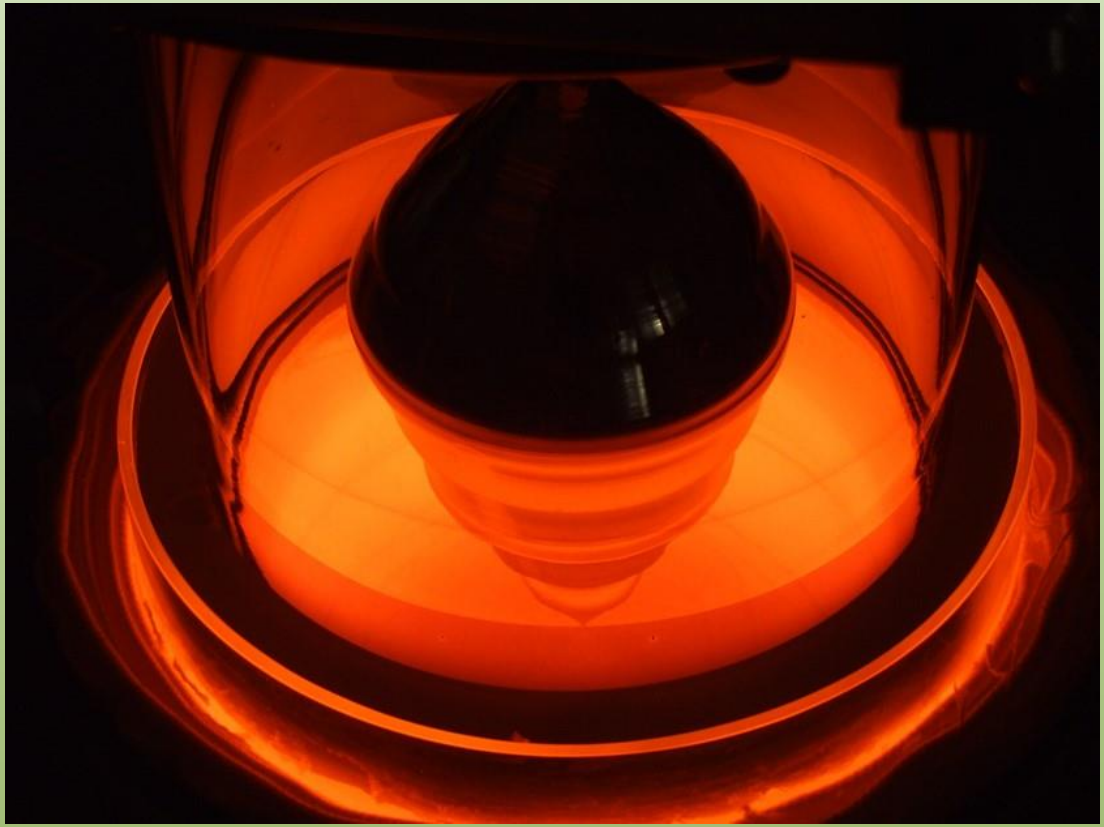
→ **On to crystals**

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

PHDS Gamma Ray 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

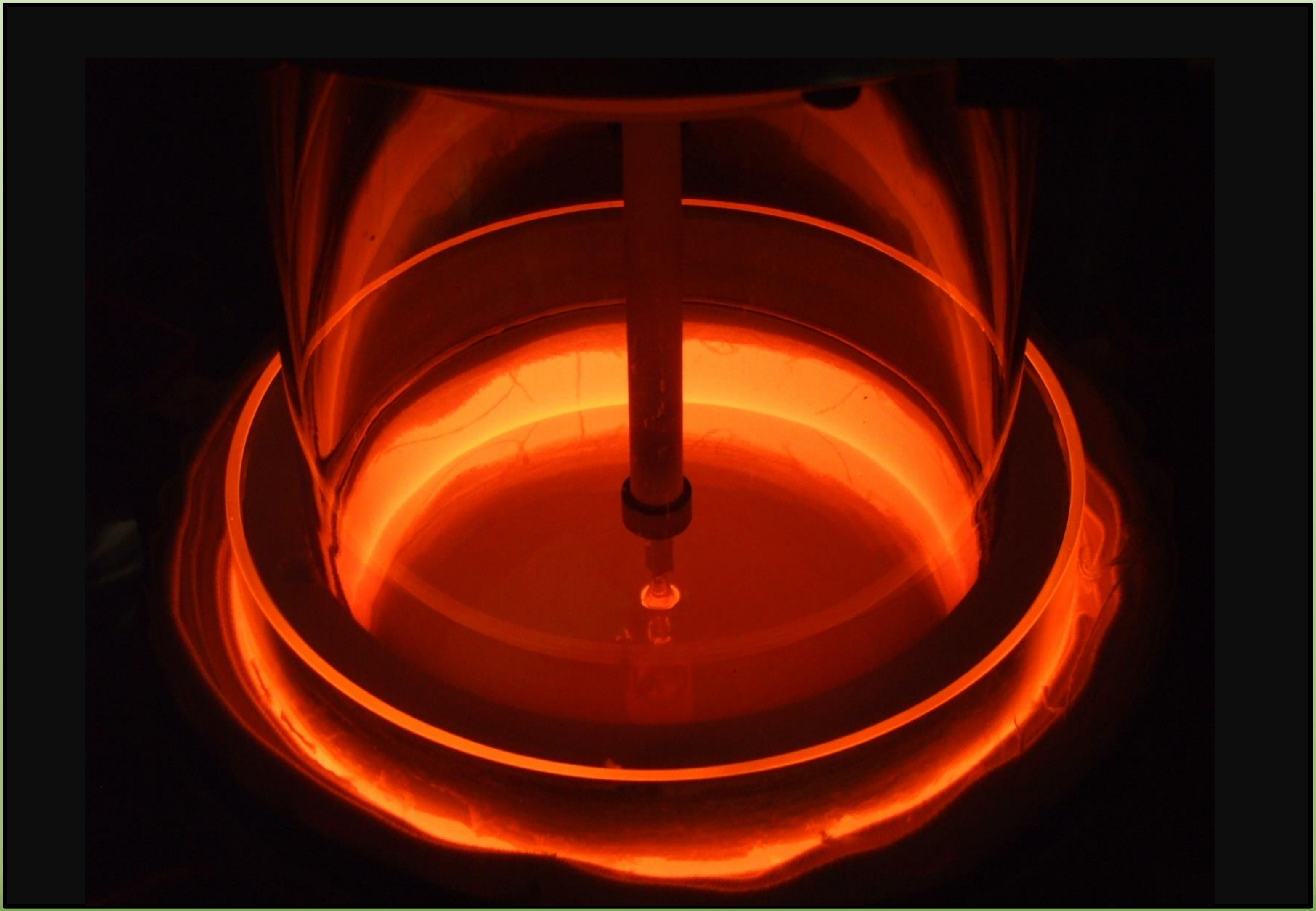
CZ250 Hemispherical quartz crucible

Growth of Crystal

Gamma Ray Detectors

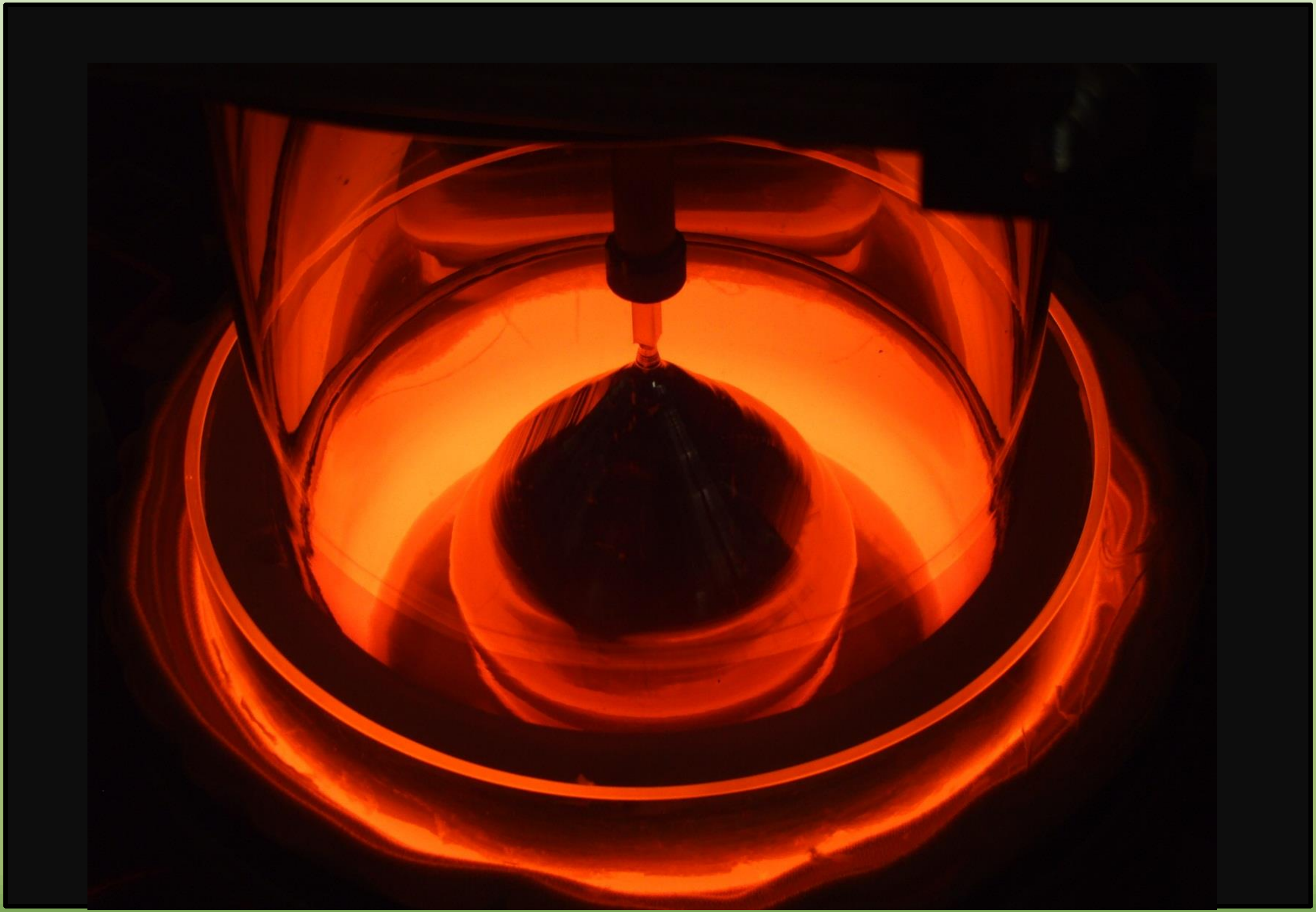
Growth of Crystal

PHDS
Gamma Ray Detectors



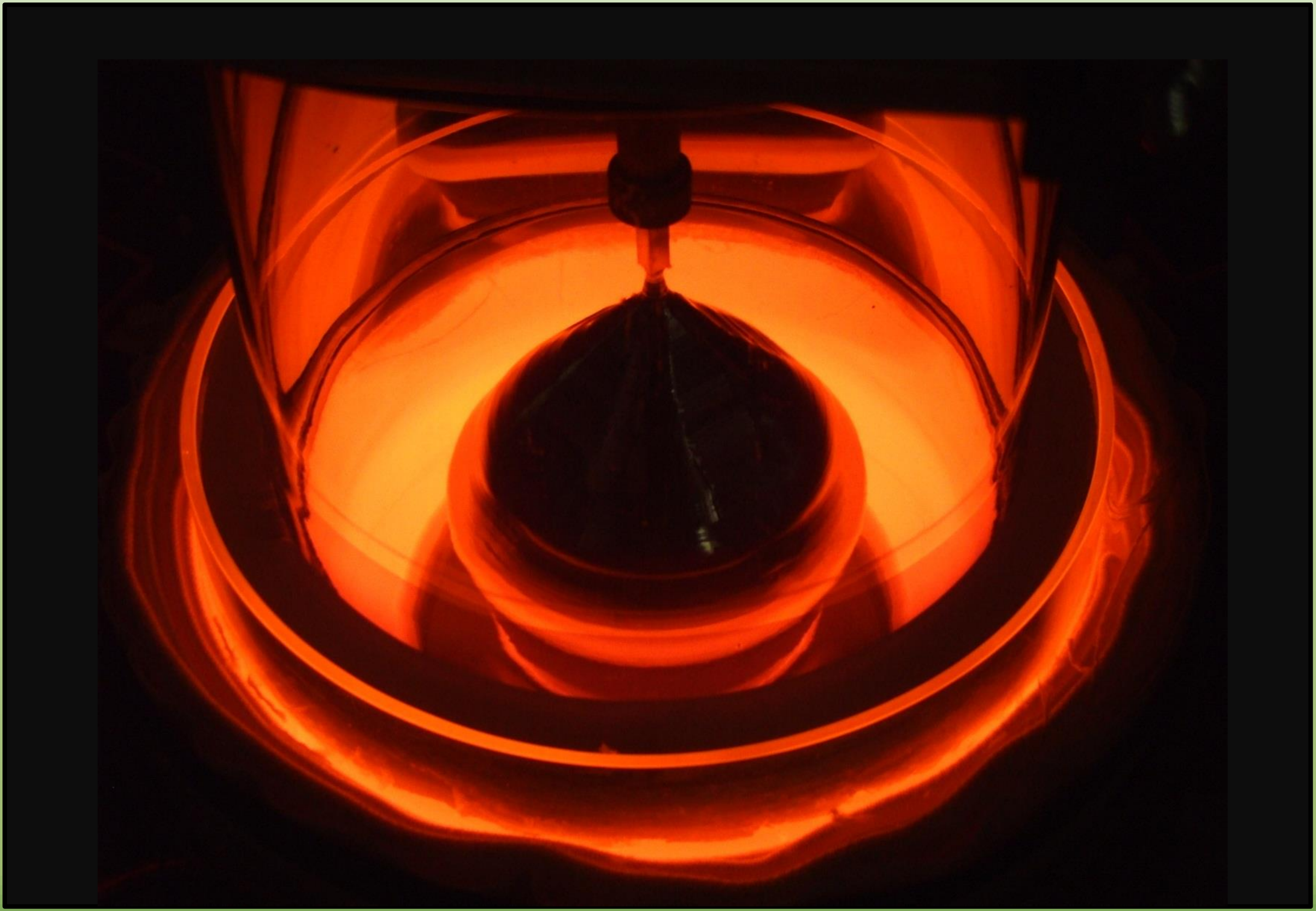
Growth of Crystal

PHDS
Gamma Ray Detectors



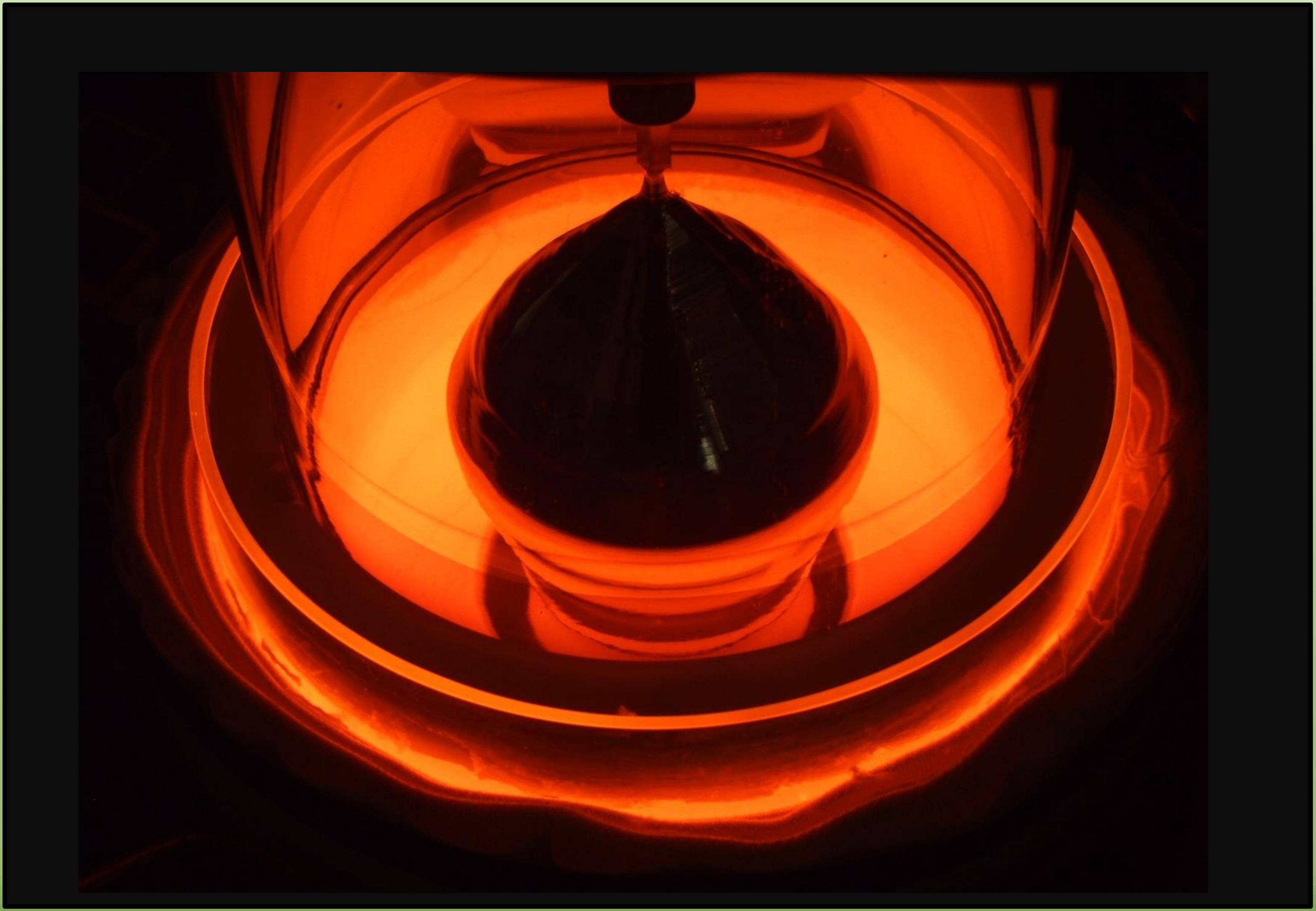
Growth of Crystal

PHDS
Gamma Ray Detectors

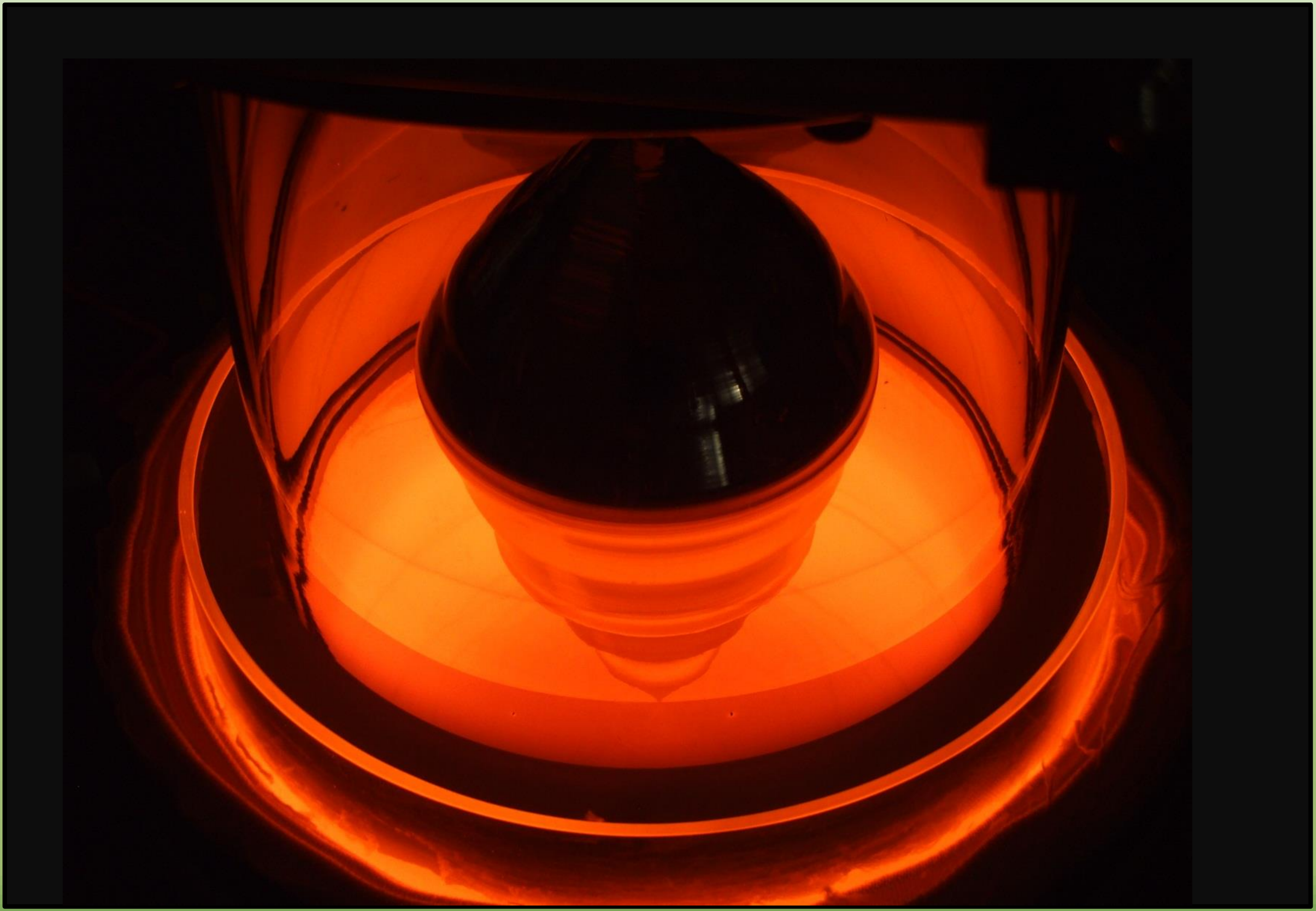


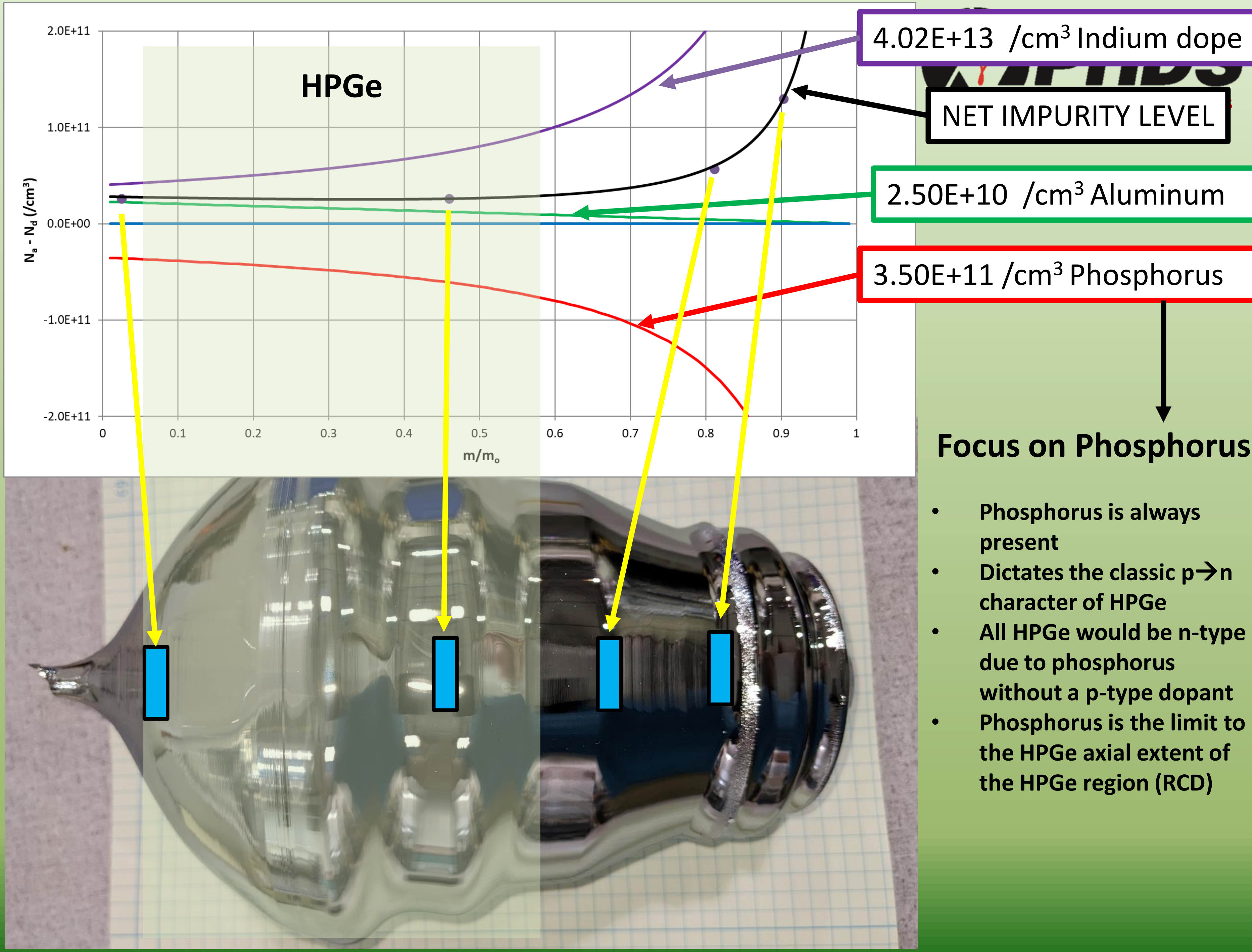
Growth of Crystal

PHDS
Gamma Ray Detectors



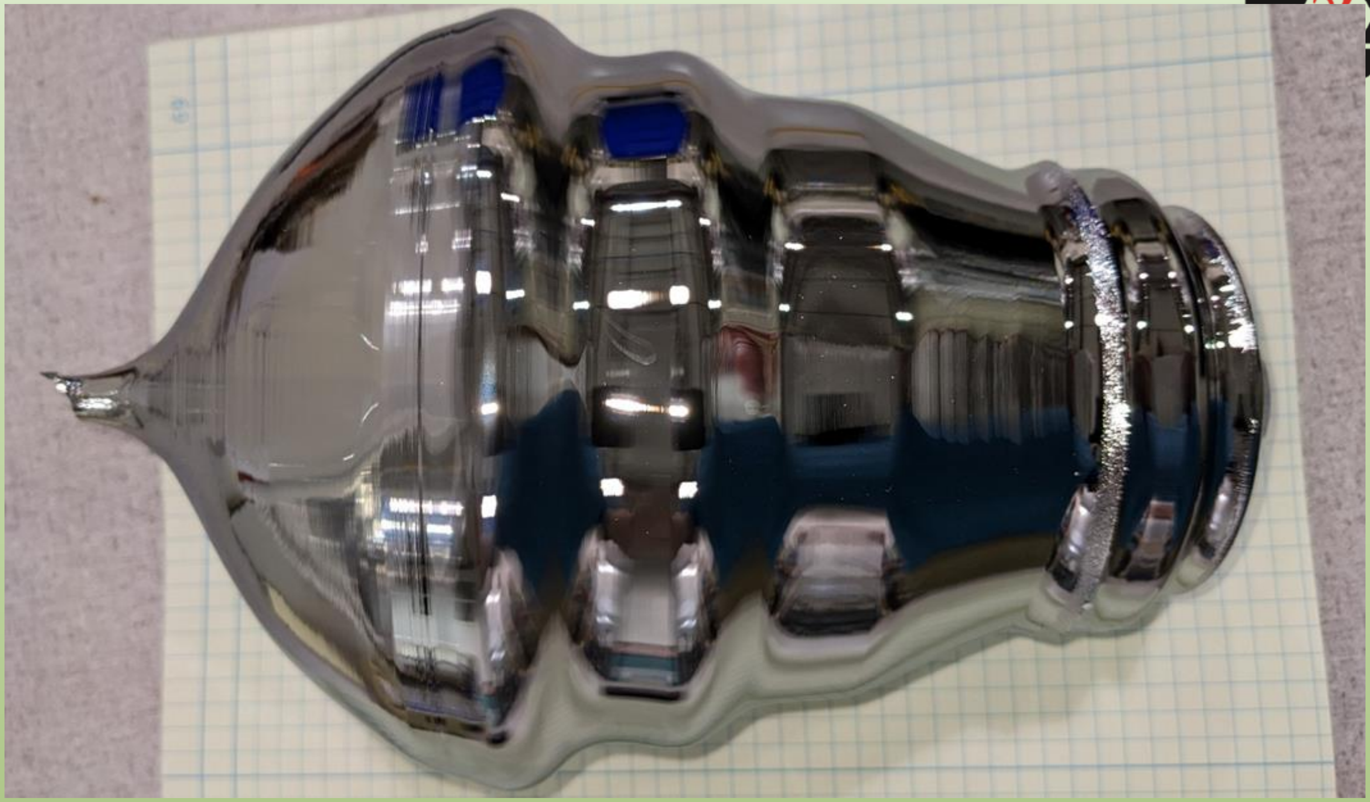
HPGe Crystal





Focus on Phosphorus

- **Phosphorus is always present**
- **Dictates the classic p→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 2-4x10^{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