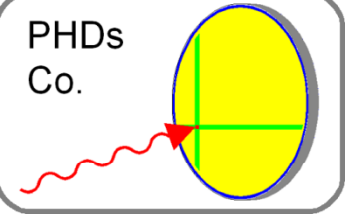


PHDs
Co.



High Purity Germanium Crystals for Low Background Counting Arrays

Principal Investigator: Ethan Hull, Ph.D.

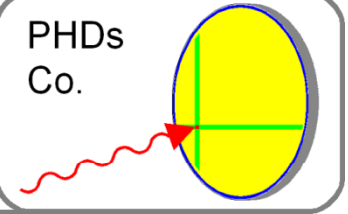
DE-FG02-08ER84987

Phase II: 8/14/2009-8/13/2011

A high-purity germanium processing system has been designed, fabricated, and demonstrated to grow high-purity germanium crystals of detector quality. The novel designs of the crystal puller and zone refinements systems provide extremely repeatable material characteristics pertinent to the fabrication of high-purity germanium detectors for low background counting experiments.

1. Brief overview of PHDs Co.
2. Phase II Program Goals
3. Progress During Phase II
 - a. Process outline
 - b. Segregation

PHDs
Co.



PHDs Co

3011 Amherst Rd, Knoxville, TN

Established Fall 2004

PHDs Co is a Tennessee C corporation

Ethan Hull, Ph.D., CEO

Richard Pehl, Ph.D., CFO

PHDs Co is a private corporation

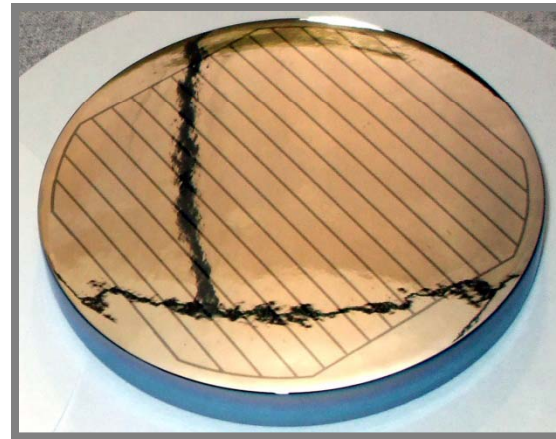
Technical Emphasis

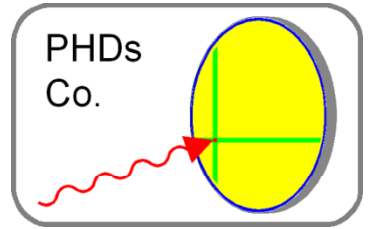
PHDs Co makes germanium semiconductor detectors

DOE Nuclear Physics – selling science detector systems

Military/Security Applications – GeGI (under development)

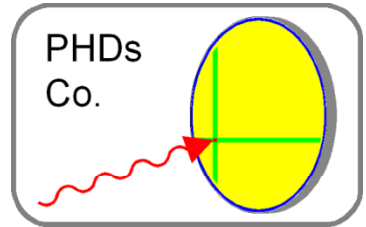
Nuclear Medicine – GGC, MIX (under development)

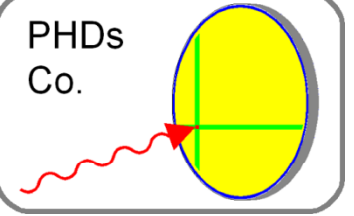




PHDs Co. Facility

Industrial zone, Knoxville, TN

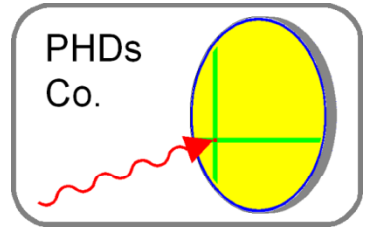




Phase I: The novel design of PHDs Co CZ250 puller is viable for HPGe
CZ250 is a unique design with the potential for better material
control – segregation.

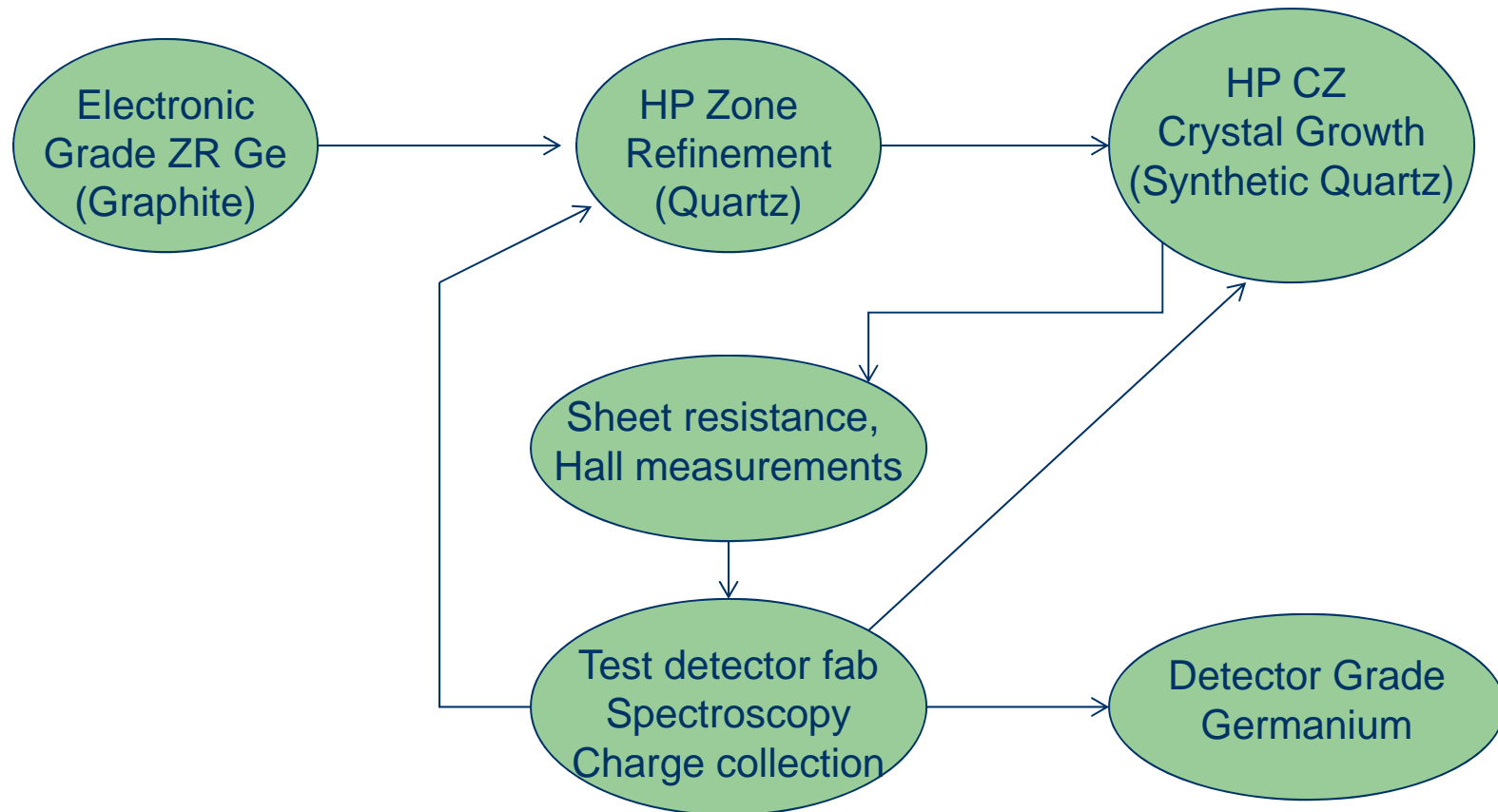
Phase II Program Goals:

1. Improve the material to detector quality
2. Study the extent to which the puller can control impurities**
 - a. Construct zone refinement (ZR) systems
 - b. Determine the merit of ZR vs. successive CZ pulls
3. Establish viability of high-purity germanium production
 - a. Modular – relatively inexpensive puller design – dedicated ^{76}Ge systems
 - b. Provide additional domestic source of HPGe for DOE research – low-background experiments like Majorana.



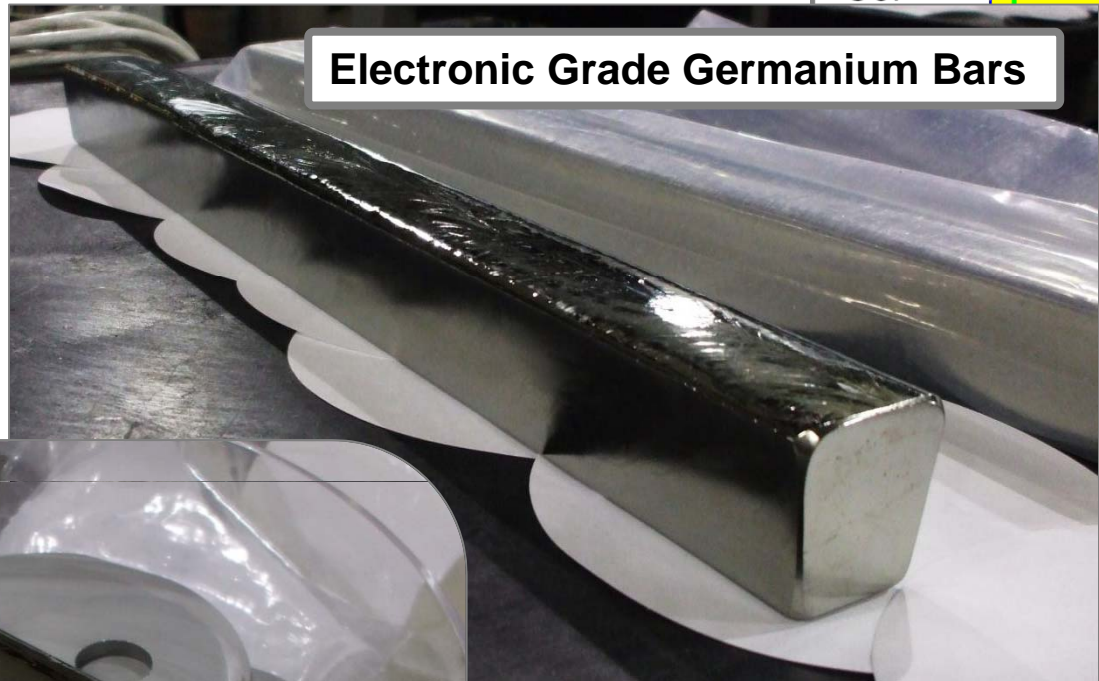
Phase II Progress

1. Process developed – review the process
2. Segregation!
3. Detector quality germanium





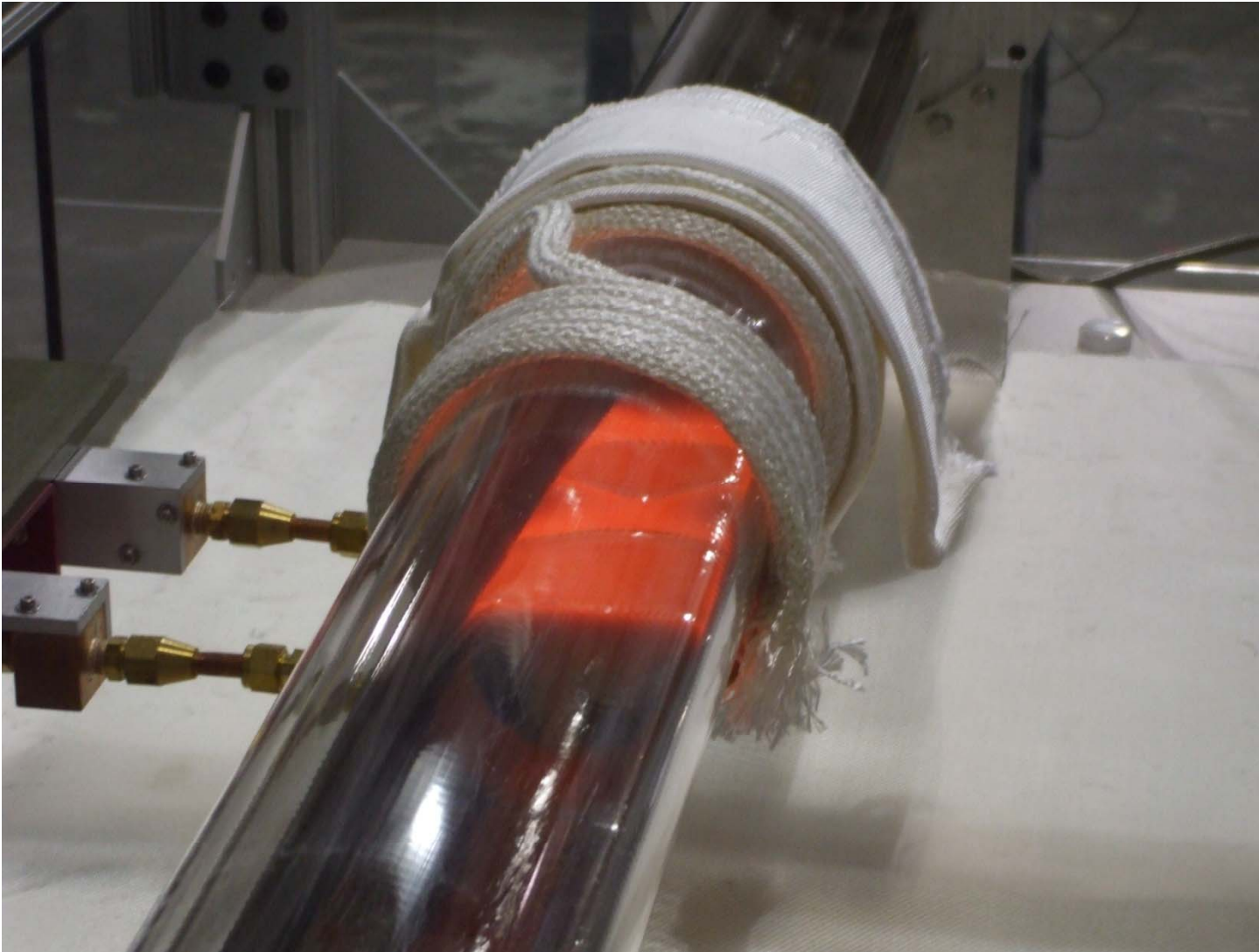
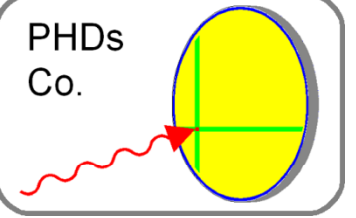
Electronic Grade Germanium Bars



HP ZR ends and Crystal Pieces

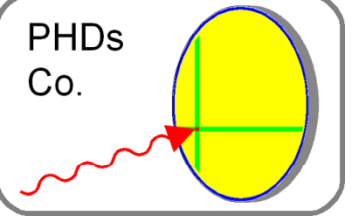
Zone Refinement Process

PHDs
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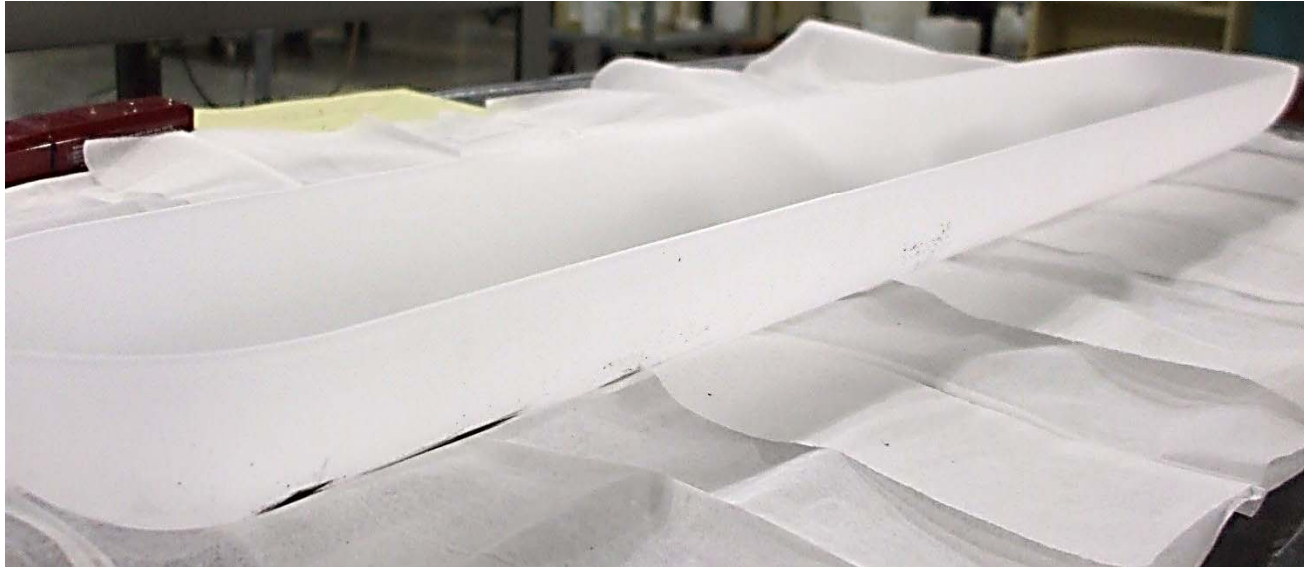


Zone Refinement Process

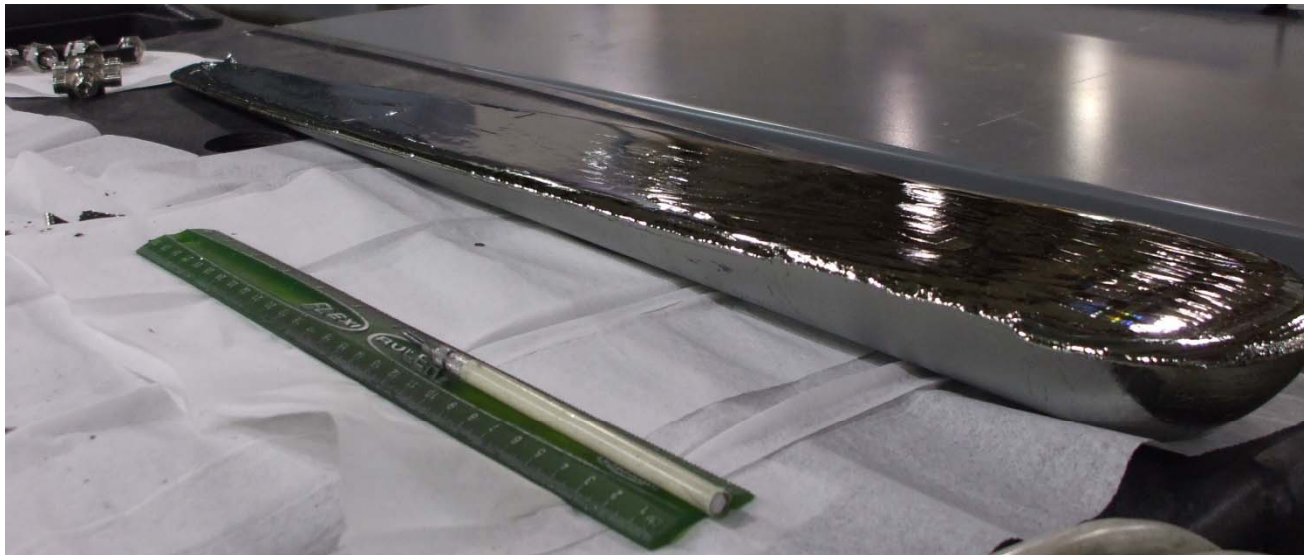
PHDs
Co.



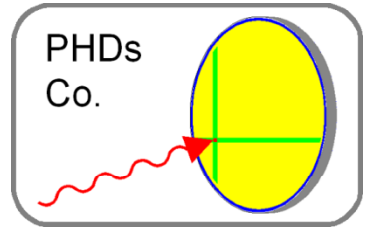
Zone Refinement Process

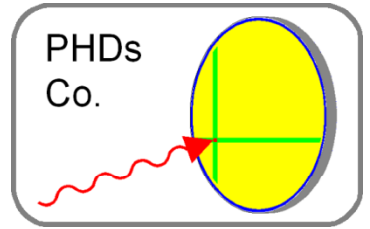


Quartz Boat



Finished HP
ZR Bar

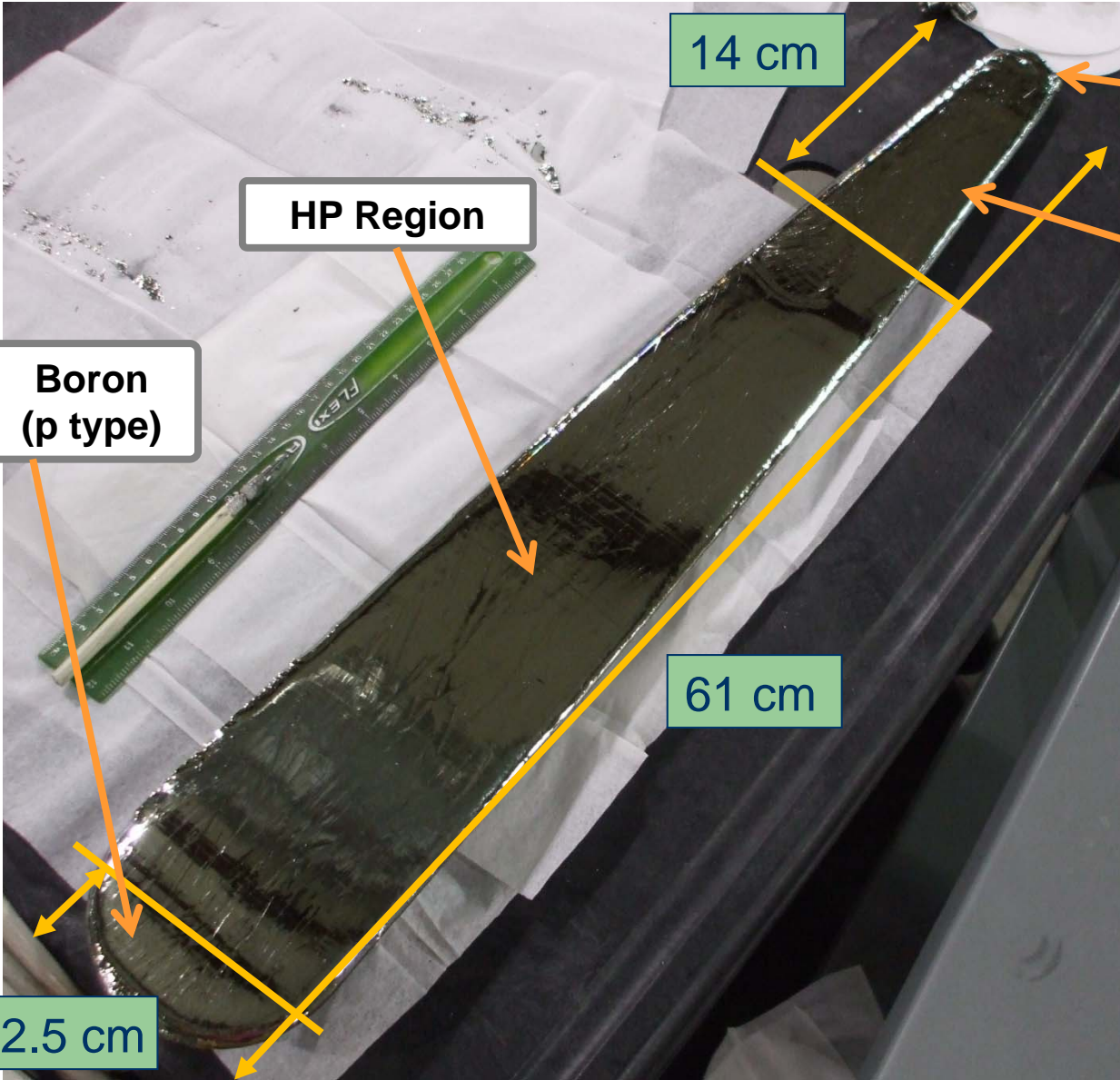




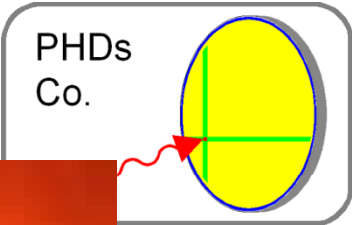
Metals (Cu,
Fe, ...)

Phosphorus
(n type)
Aluminum
(p-type)

ZR Bar is
Cropped



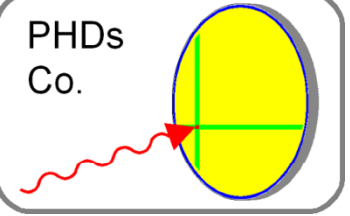
Czochralski Growth Process



Czochralski Growth Process

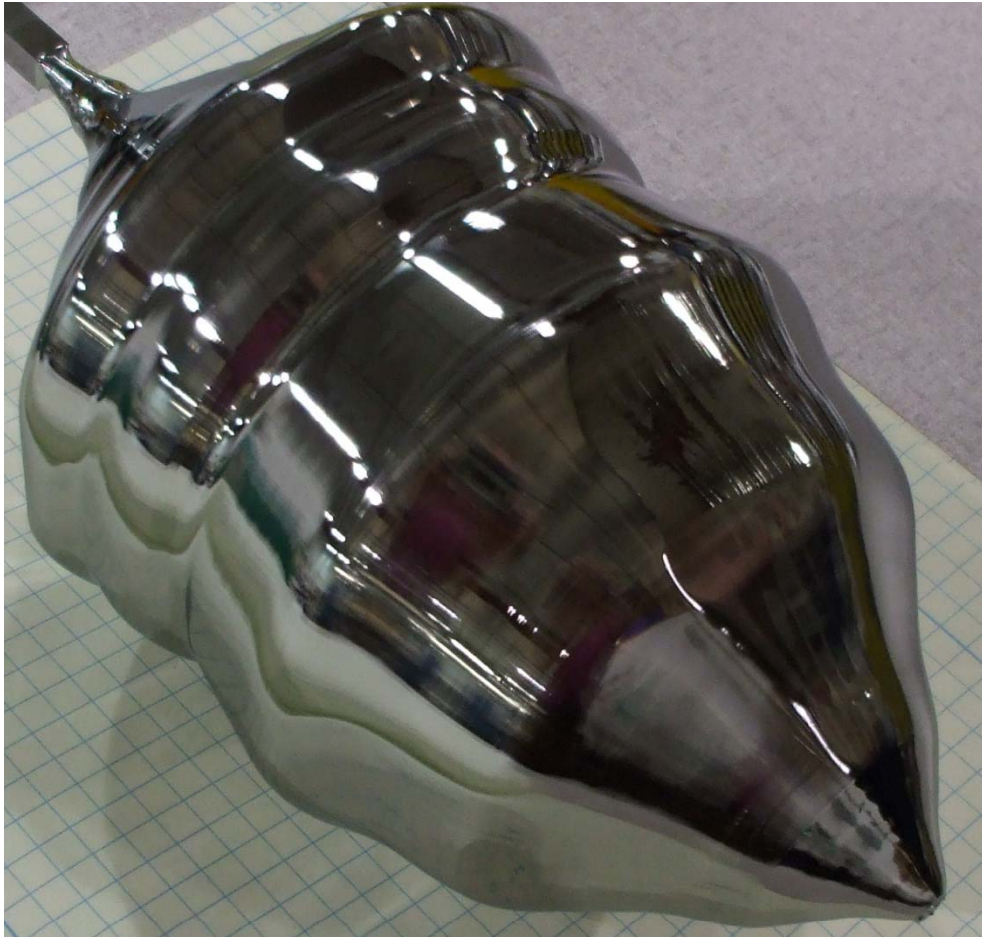
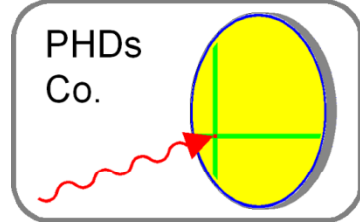


PHDs
Co.



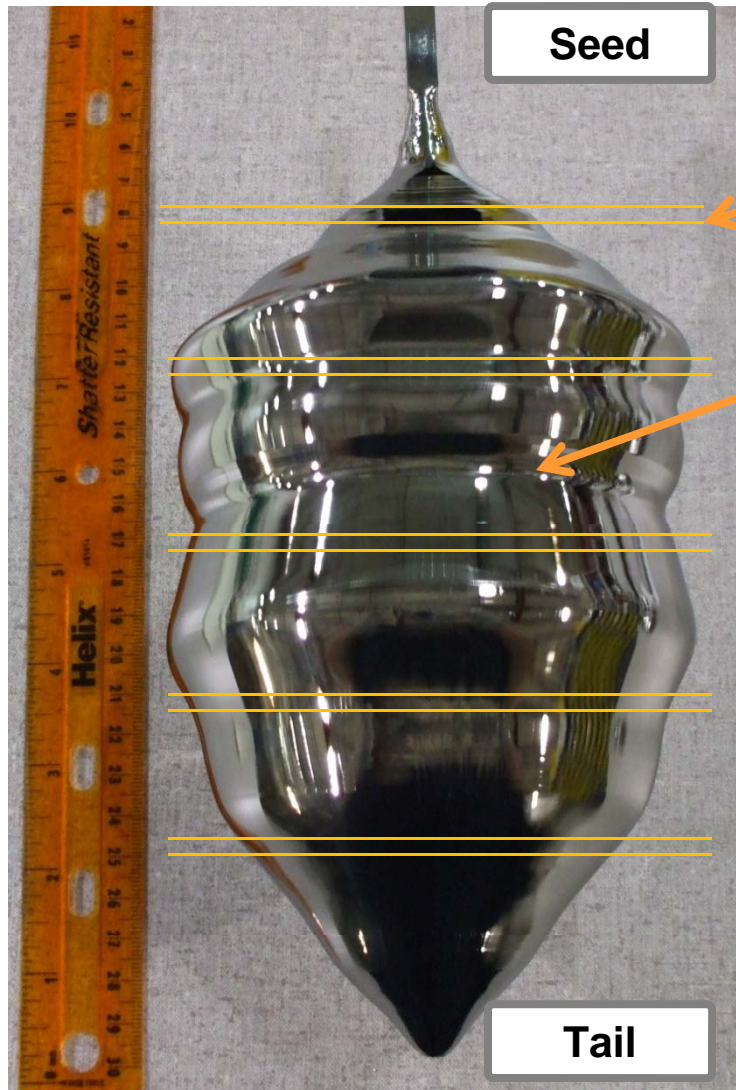
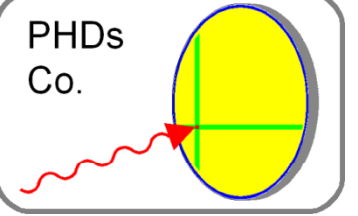
Czochralski Growth Process

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Slicing

PHDs
Co.



Seed

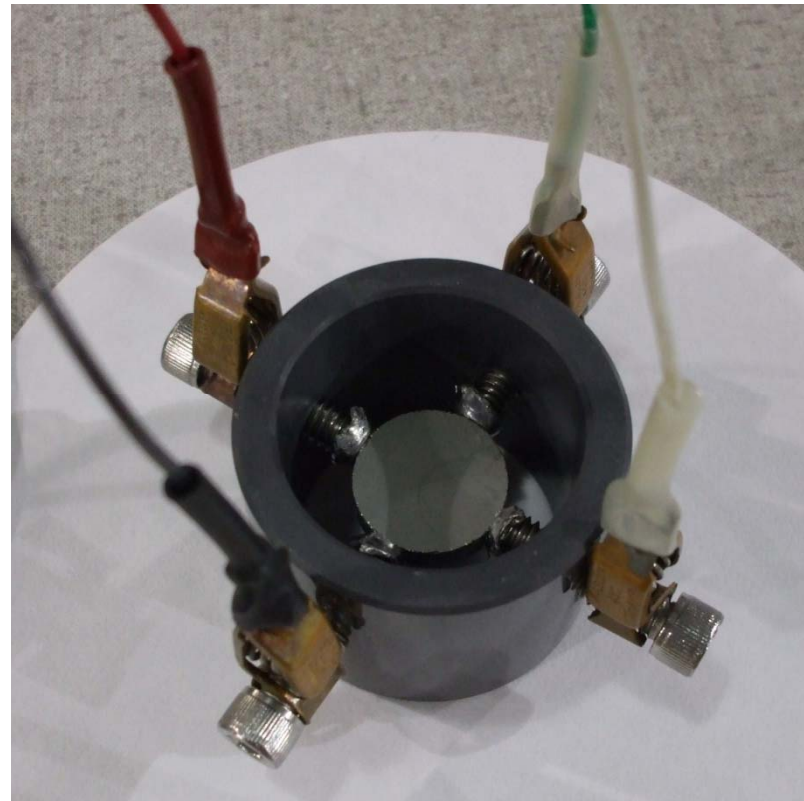
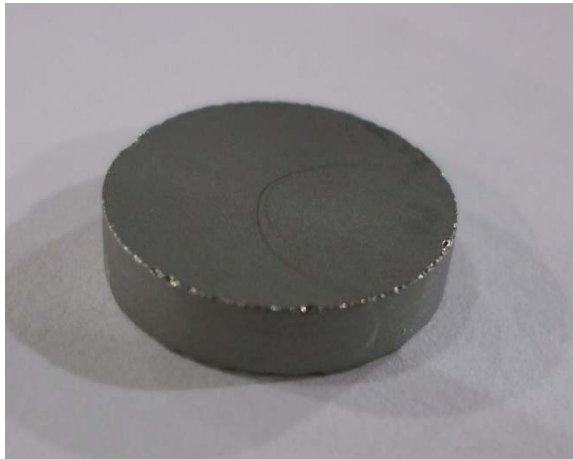
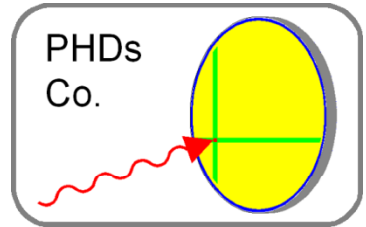
5-mm thick evaluation slices

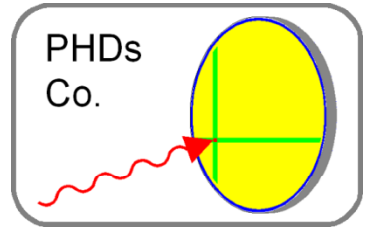
Large pieces for detectors

Tail

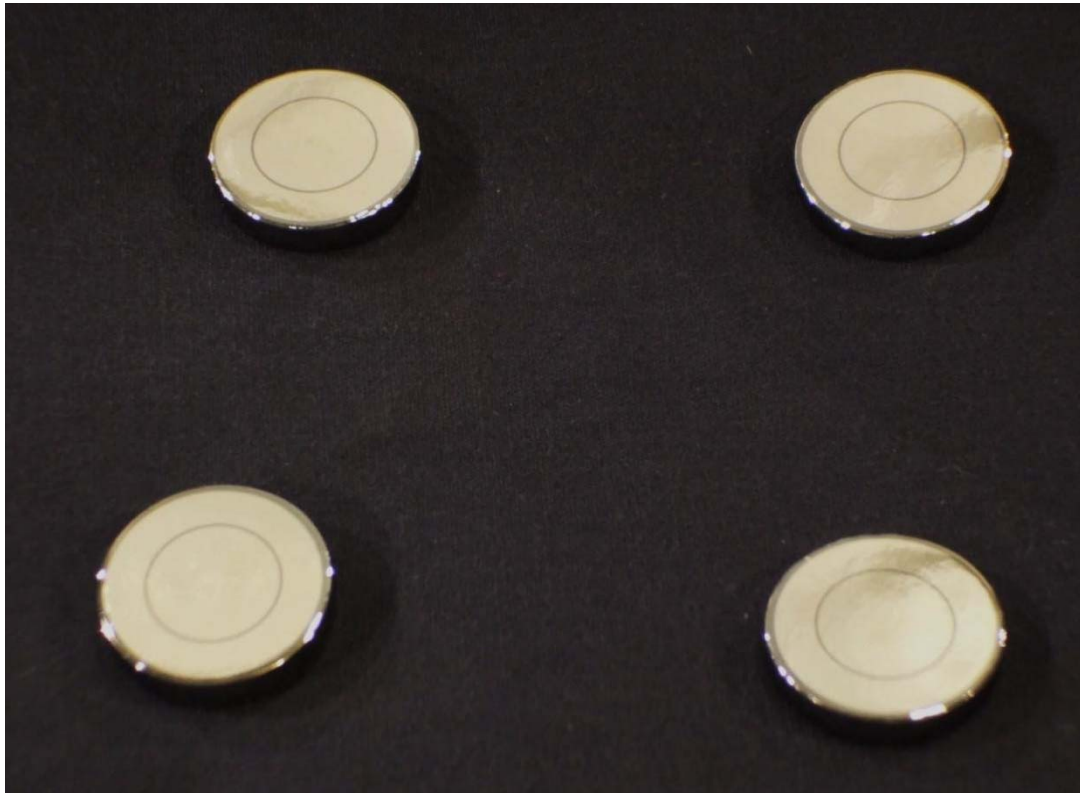
Germanium Sample Measurements

- van der Pauw sheet-resistance measurements $\rightarrow |N_A - N_D|$
- Hall measurement $\rightarrow n$ or p type

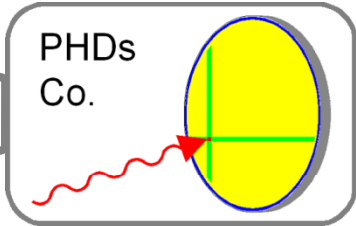




Detector measurements rule → All important charge collection!!



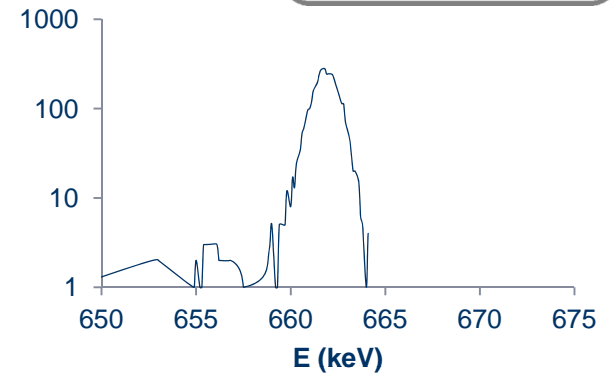
Gamma-ray spectroscopy is the most pertinent measurement



**122-keV FWHM
= 1.09 keV**



$1.1 \times 10^{10} / \text{cm}^3$



**662-keV FWHM
= 1.39 keV**

**F = 0.08
Perfect!**

