Growth of large diameter high-purity germanium crystals for Nuclear Physics research

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DE-SC0004256 Richard Pehl PI

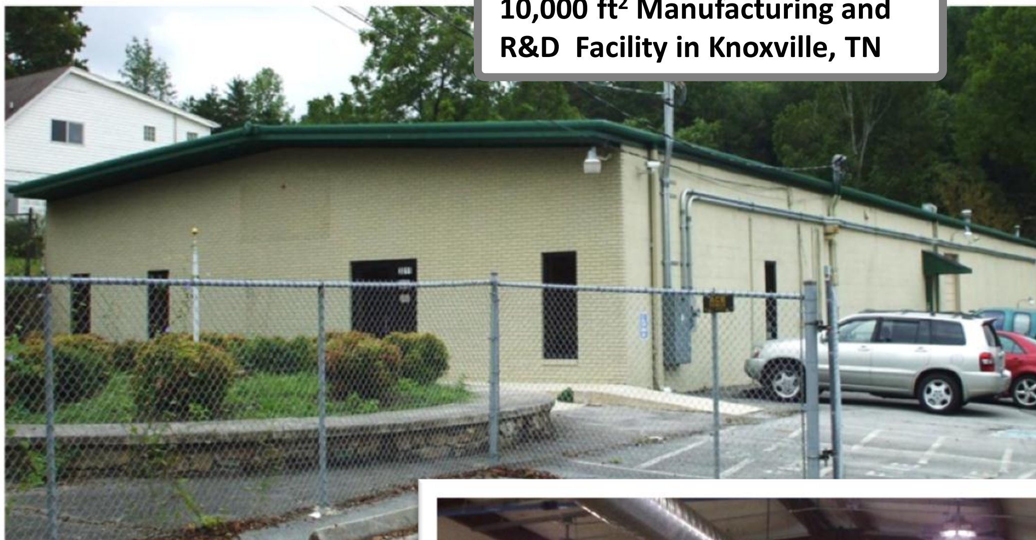
8/15/2011-8/14/2014 (including NCE)

Extremely large diameter high-purity germanium crystals are being developed for large diameter segmented Nuclear Physics planar detectors. A high-purity germanium crystal puller has been demonstrated to grow crystals having sufficient purity and charge-collection properties to produce detector-quality germanium. The crystal diameter and purity levels have been iteratively improved to produce several successful commercial detectors delivered to customers during the past year. Significantly larger diameter germanium crystals have been grown with the correct properties for successful detector yield. These larger prototype detectors are being fabricated.

Collaboration with Kim Lister at UMass Lowell

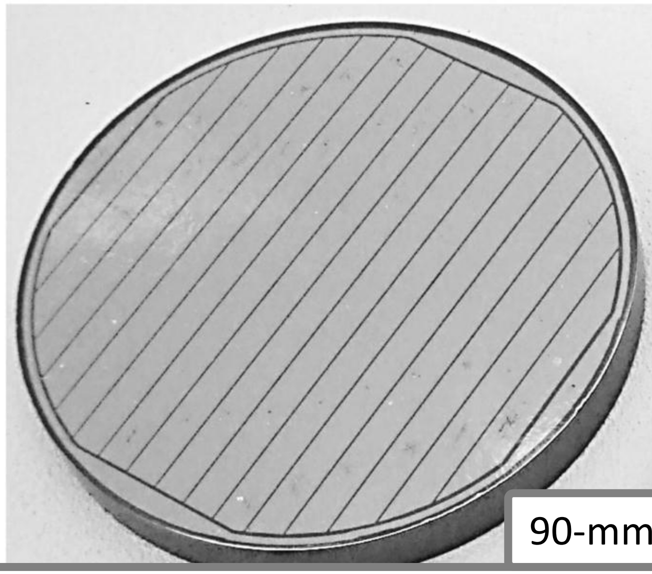
- Introduction to PHDs Co.
- Motivation
- Large diameter germanium process and crystal growth
  - Established commercial viability of 90-mm PHDs Co. HPGe!!
- Increasing the diameter further → 140 mm
- Material understanding – Al –Si example

10,000 ft^2 Manufacturing and R&D Facility in Knoxville, TN



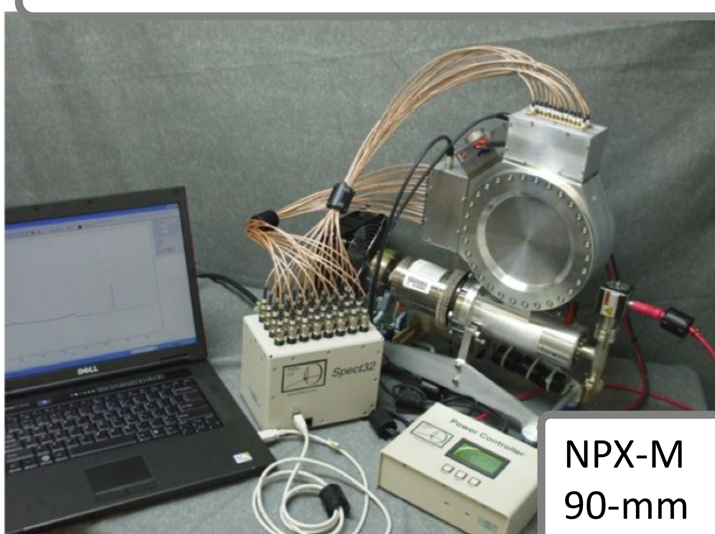
Office area (~ 2000 ft^2)

Technical area (~ 8000 ft^2)

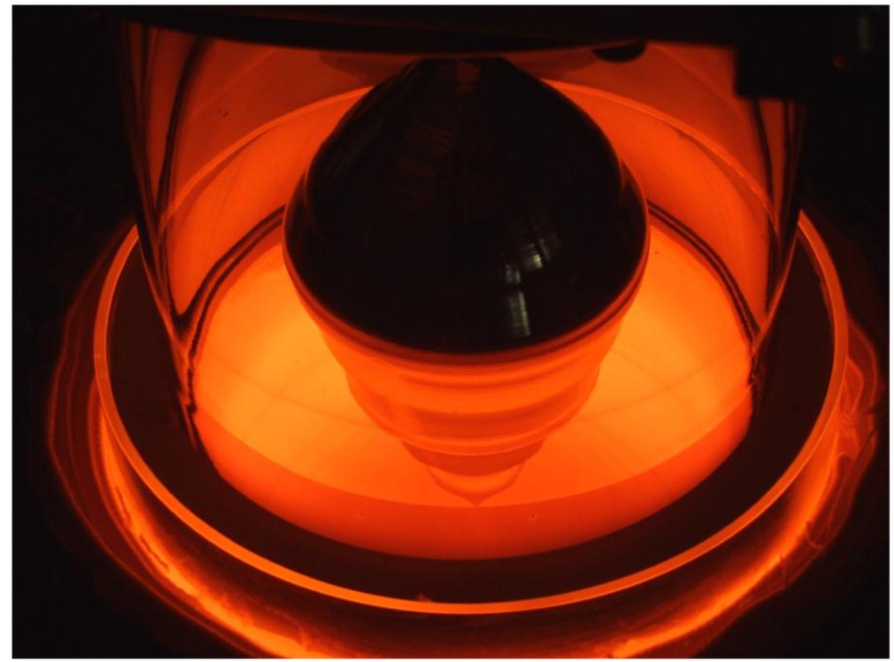


90-mm

Goal: Grow significantly larger diameter HPGe crystals for larger diameter detector systems



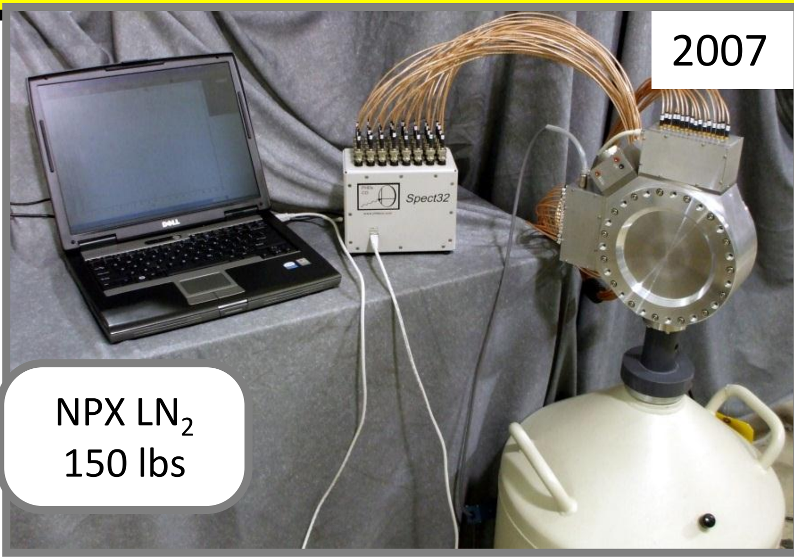
NPX-M
90-mm



Motivation:

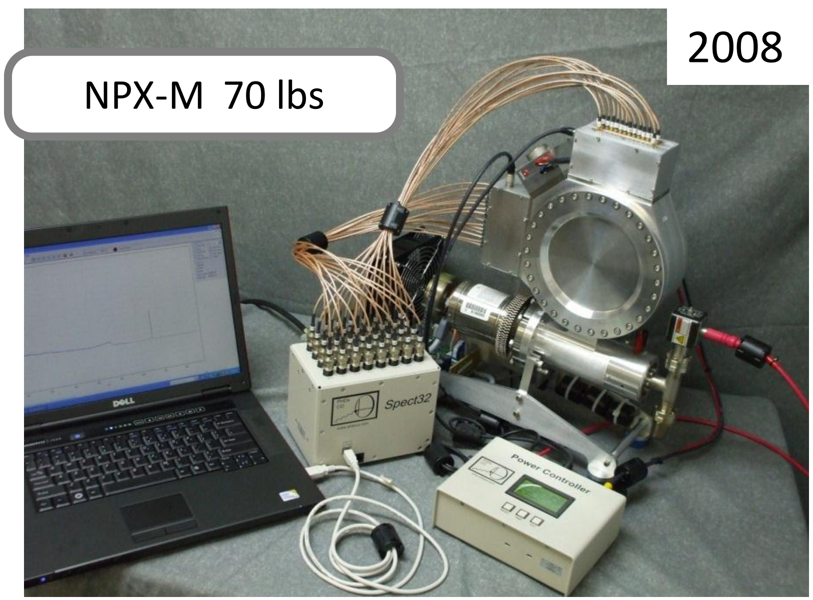
- Greater detection efficiency/system
- Less edge – more detector
- Higher detector proportion
- Lower cost per active volume and area

System Progression



2007

NPX LN_2
150 lbs



2008

NPX-M 70 lbs

2010

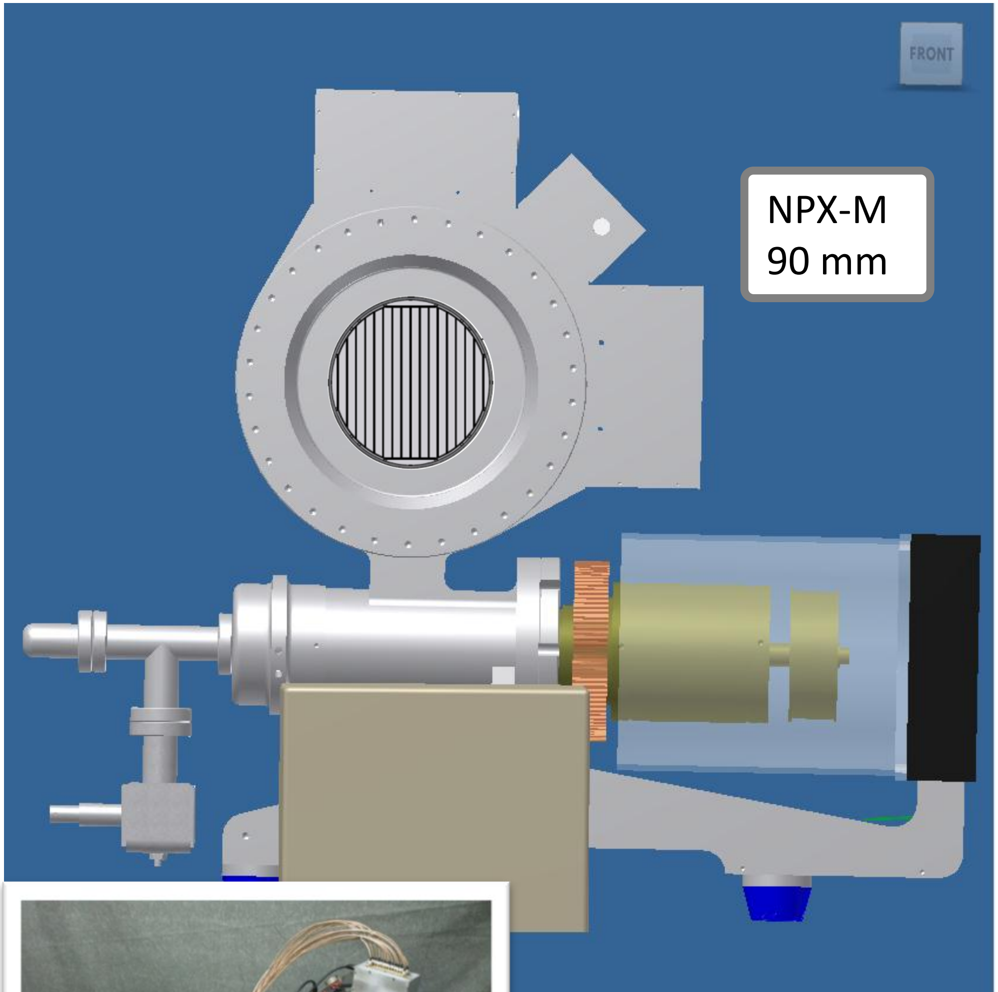
GeGI-1 55 lbs

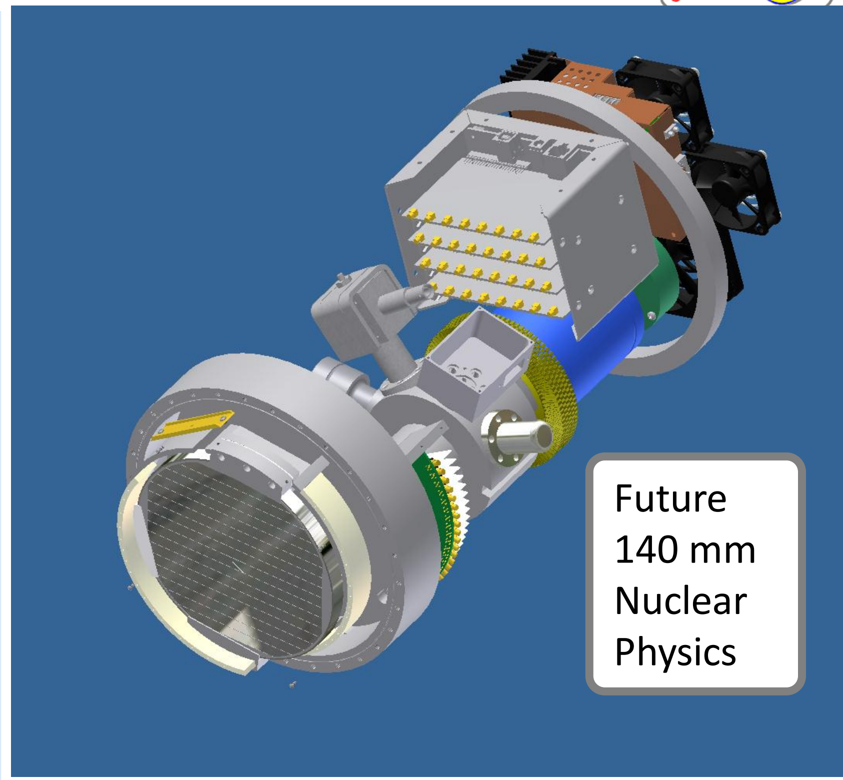
GeGI-3 33 lbs

2012

2014

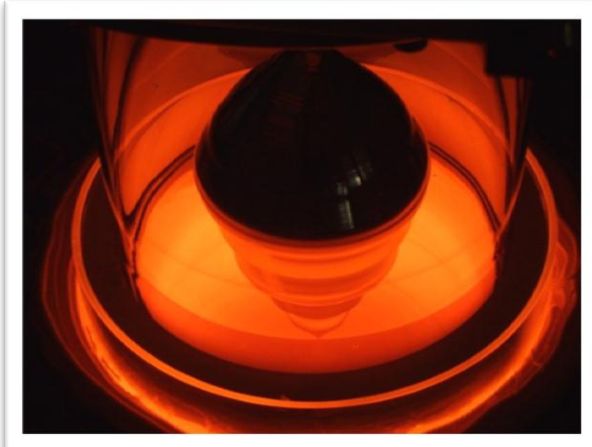
GeGI-4 28 lbs





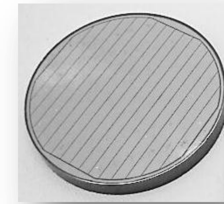
2.5 times the detector and half the supporting hardware

PHDs Co.



SPG

GeGI



90-mm

Summary of Accomplishments

- Solved some large-diameter challenges ~ N(r) – Acceptors
- Lowered Impurity concentration to tolerable levels
- Established a viable doping method
    - Sources of contamination
- Improved understanding of electron trapping – continues evolving

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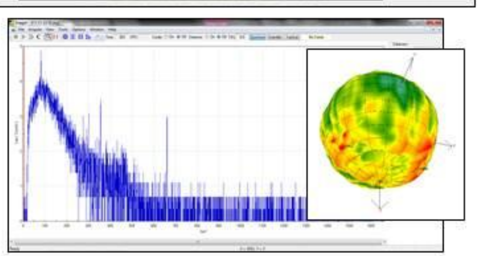
- **Transitioned 90-mm HPGe to commercial level – repeatable.**
    - **NPX Prototypes, then GeGI and GGC systems**
    - **GeGI product becomes viable – now marketing**
- **Larger crystals → Goal 140-mm diameter**
    - **Grown diameters as large as 170 mm**
    - **Grown mass as large as 15 kg**
        - **Desirable intrinsic crystal properties exist at large size**

GeGI Shipped first product spring 2013 – Enabled by this crystal program

New Product !!

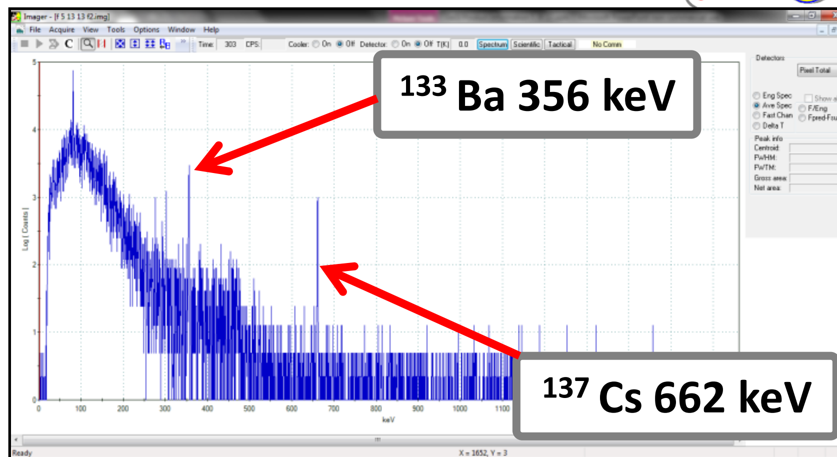
PHDs Co.

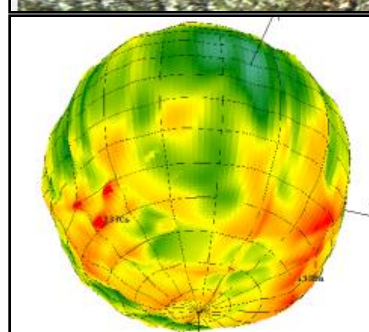
GeGI *The* ***Germanium Gamma Ray Imager***



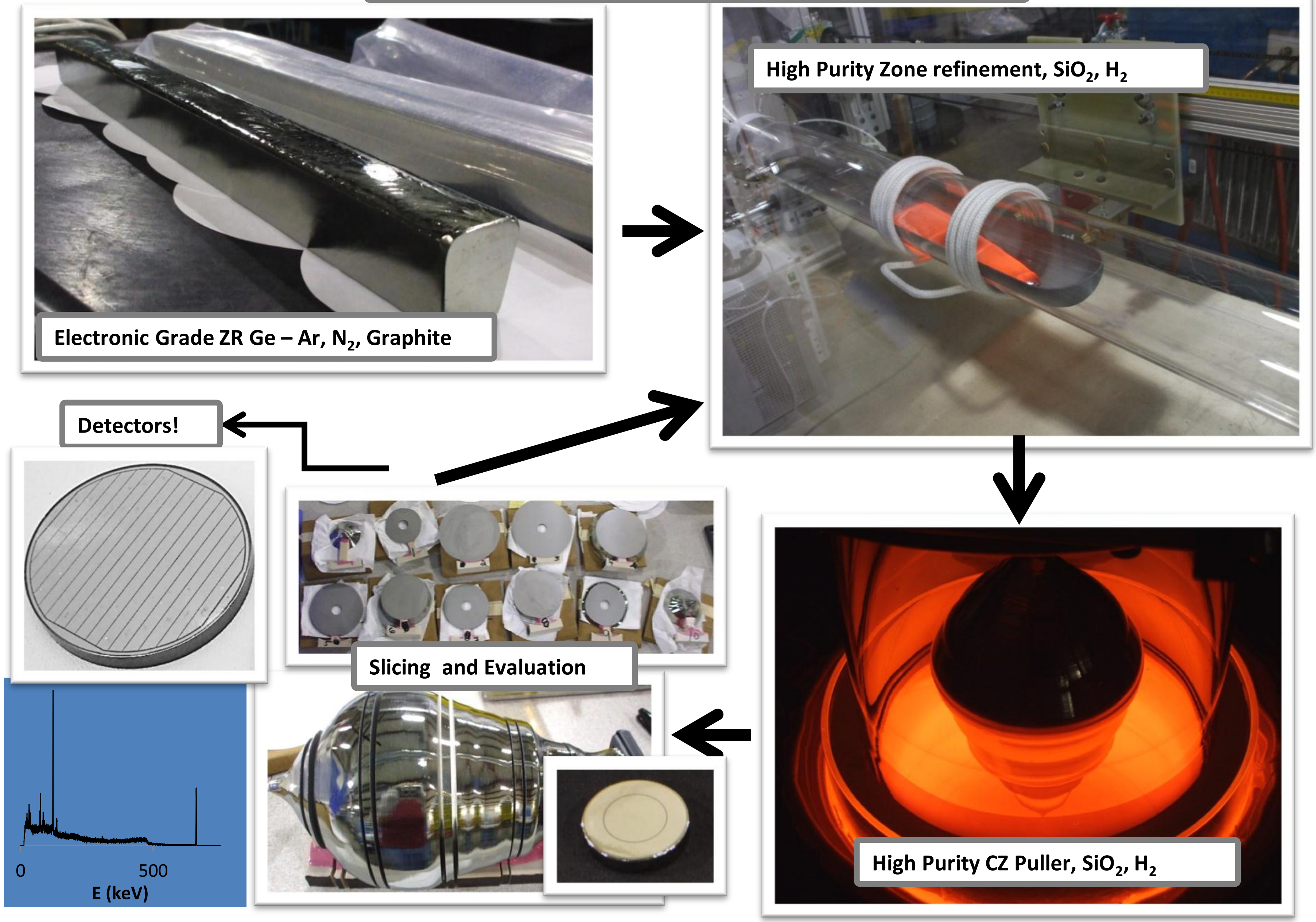
- Complete Spectroscopy *and Imaging* System
- Compton-Vision Tactical Output
- 90-mm diameter 10-mm thick Ge crystal grown by PHDs Co.
- 55 cm^2 active detector area inside guard ring
- 122-keV energy resolution FWHM ~ 1.3 keV
- 662-keV energy resolution FWHM ~ 2.2 keV
- Locates and identifies 100 μCi of ^{137}Cs in 5-10 sec at 1 meter
- Locates and identifies Special Nuclear Material (SNM)
- Data acquisition runs under Windows
- ANSI 42.42 output format
- User friendly operation
- Portable 33 lbs
- Includes an internal battery (30-45 minutes)

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



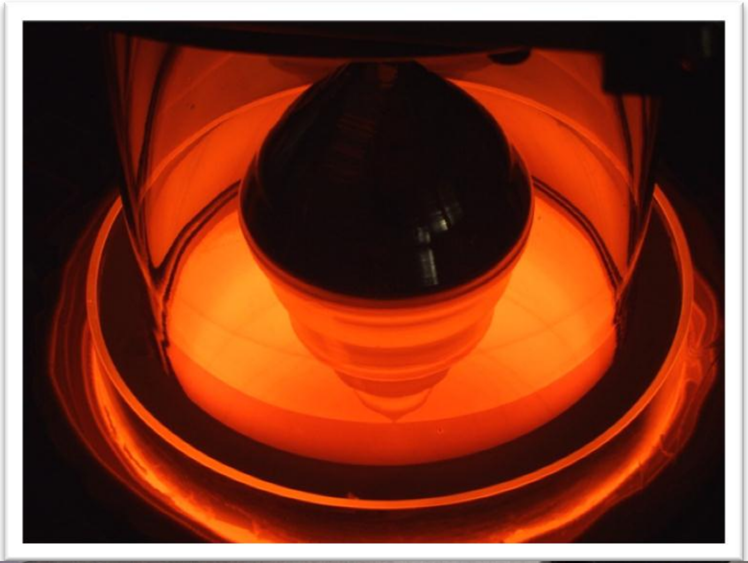


Detector-Grade Germanium Process

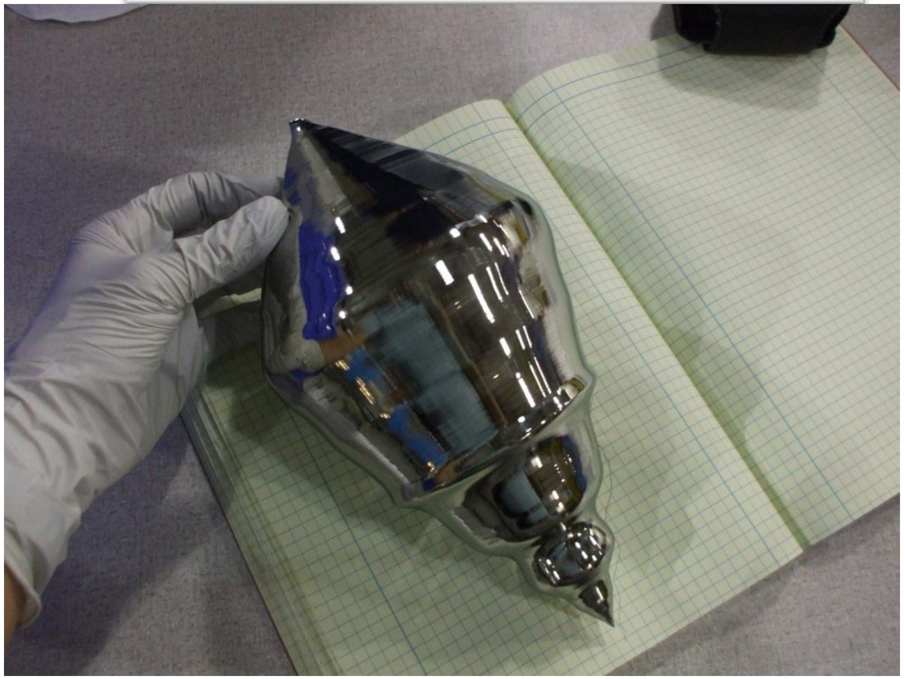


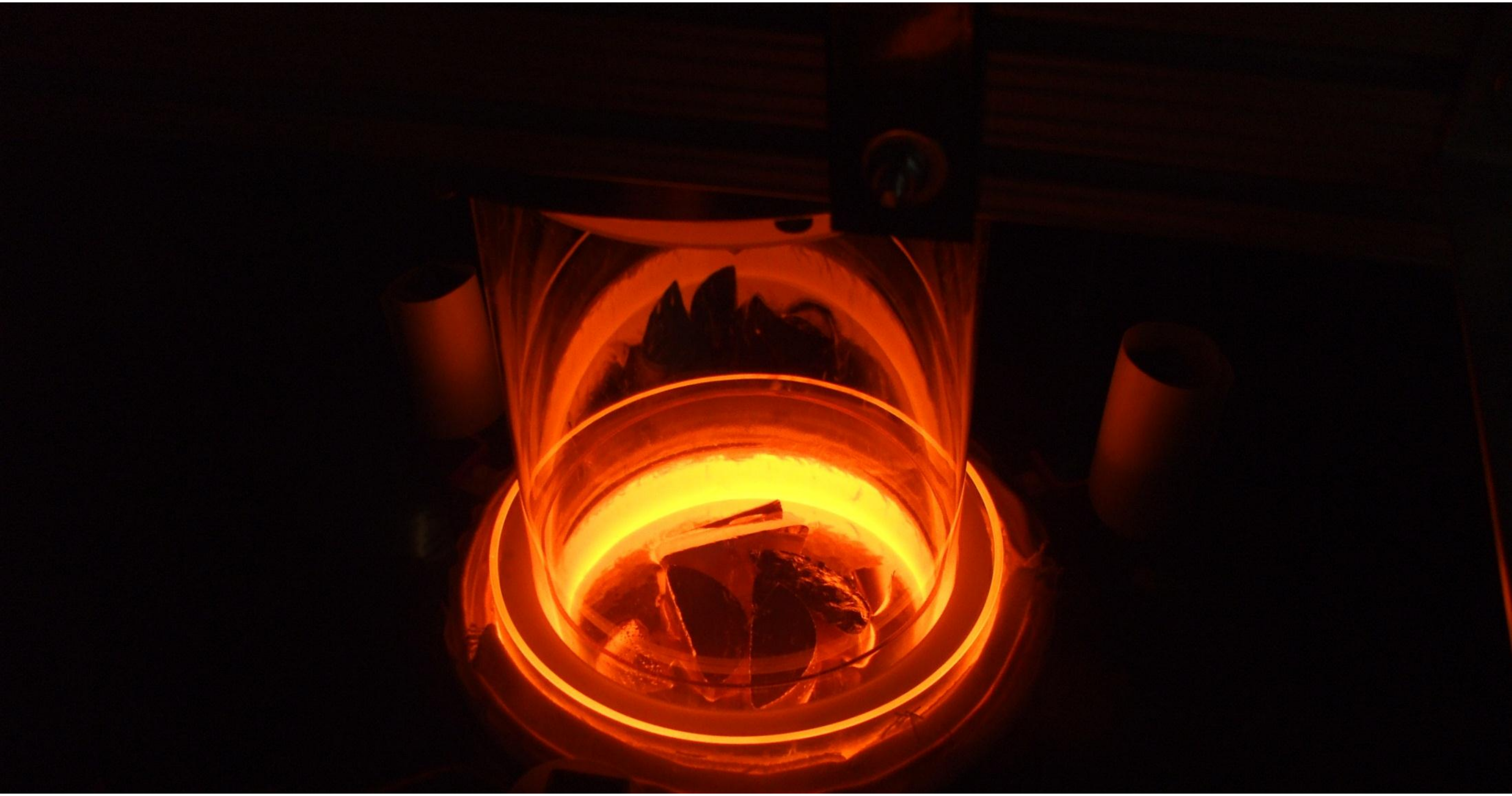
Increasing crystal diameter and mass

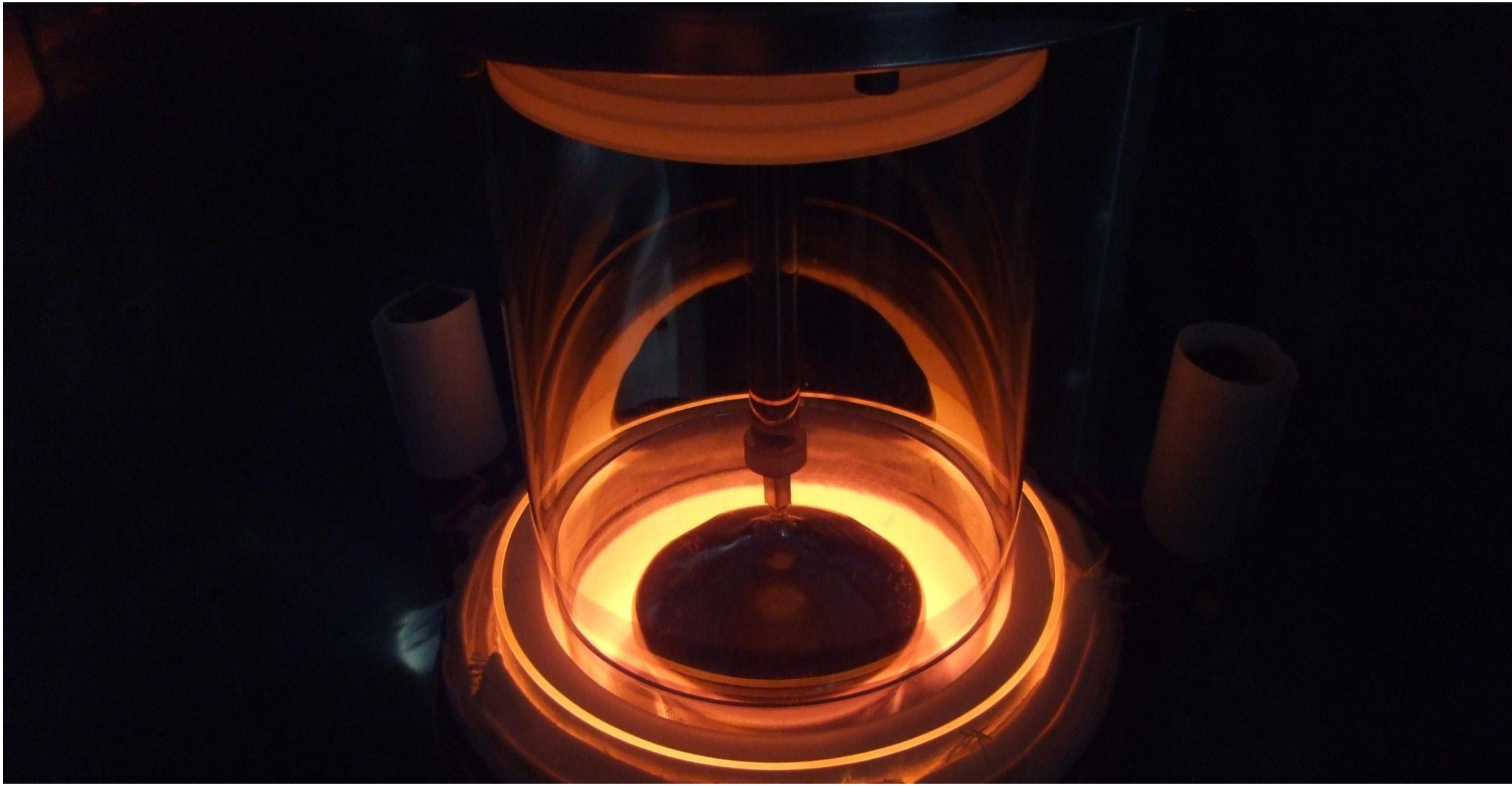
PHDs
Co.



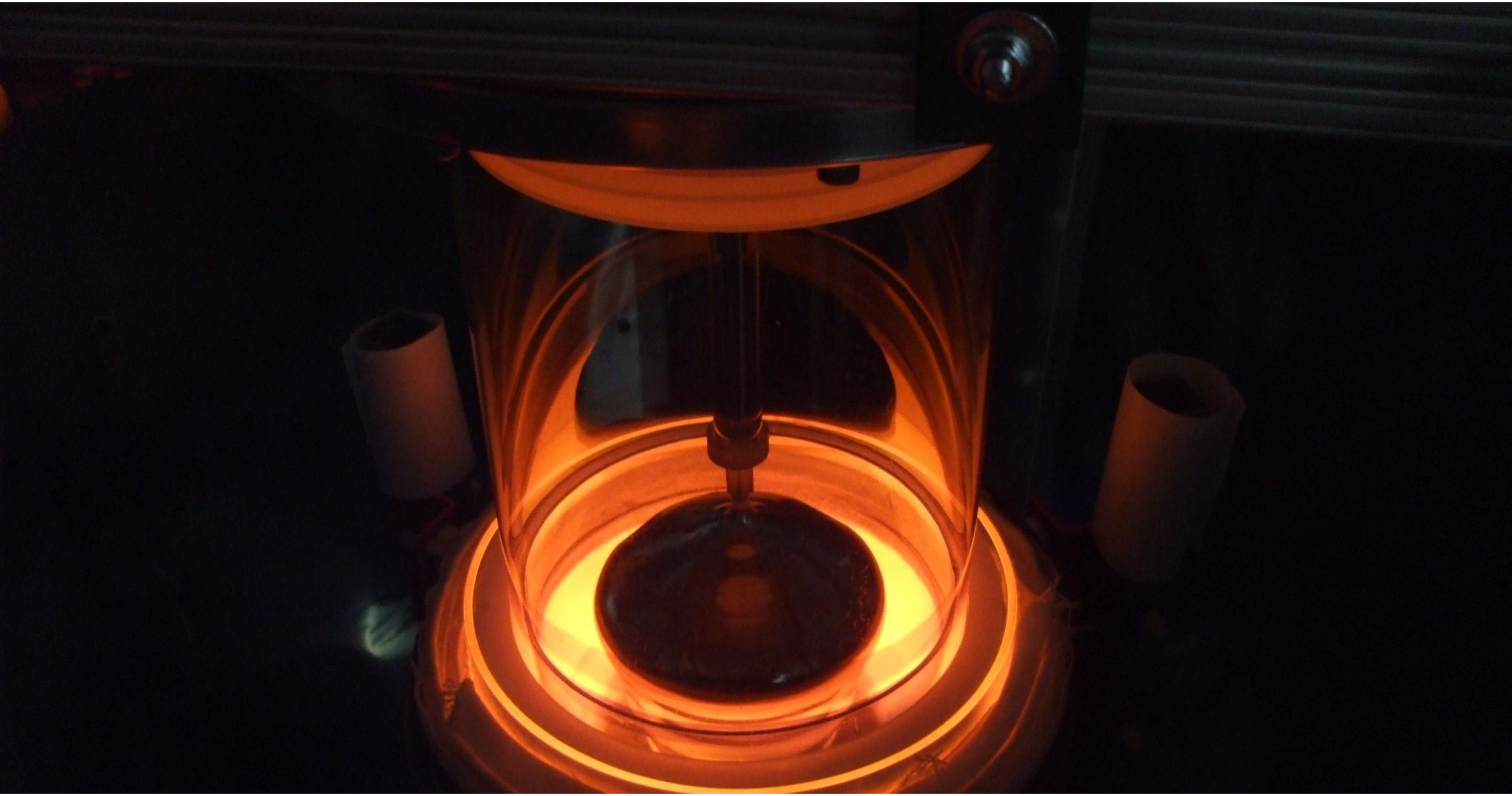
10 kg Crystal
(from last year's presentation

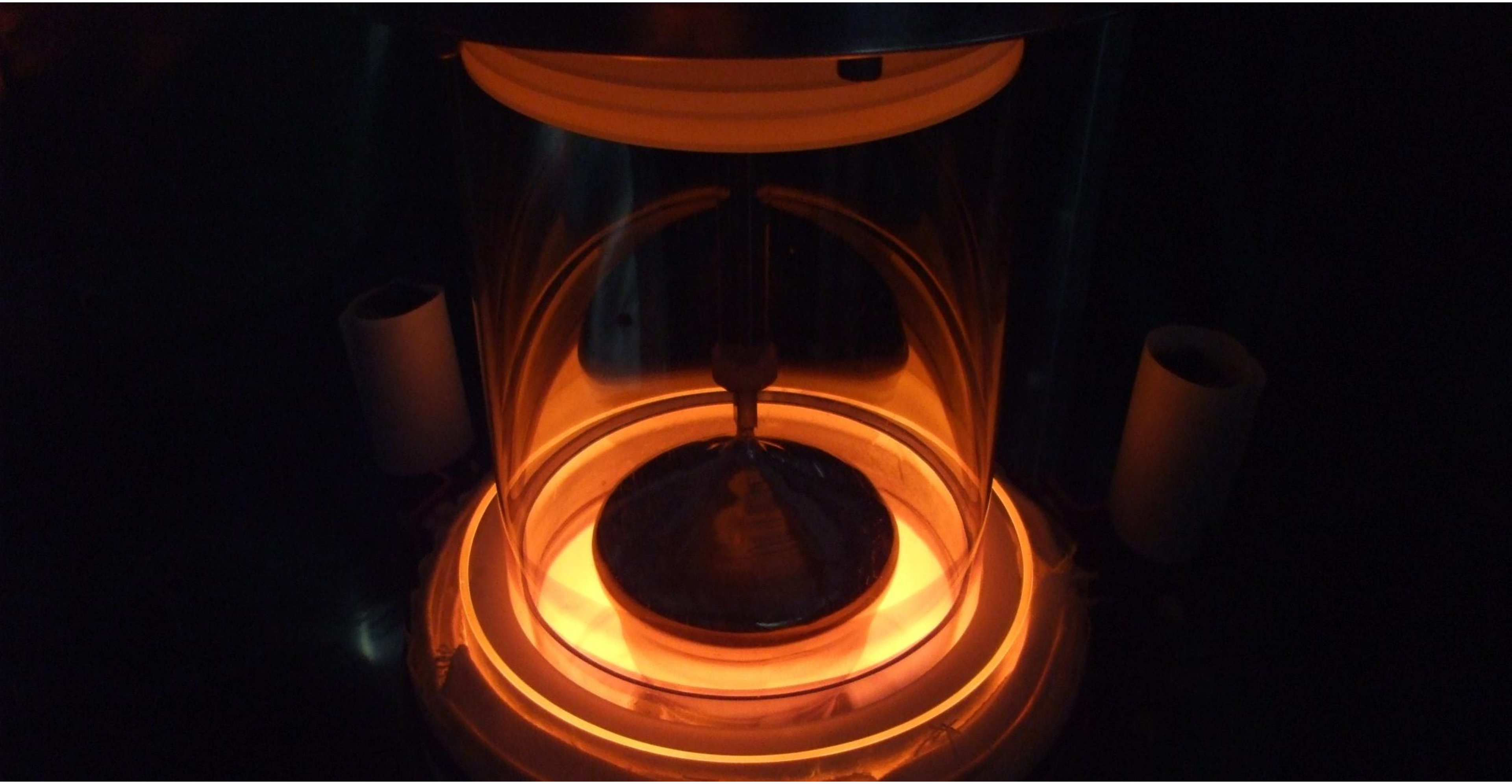




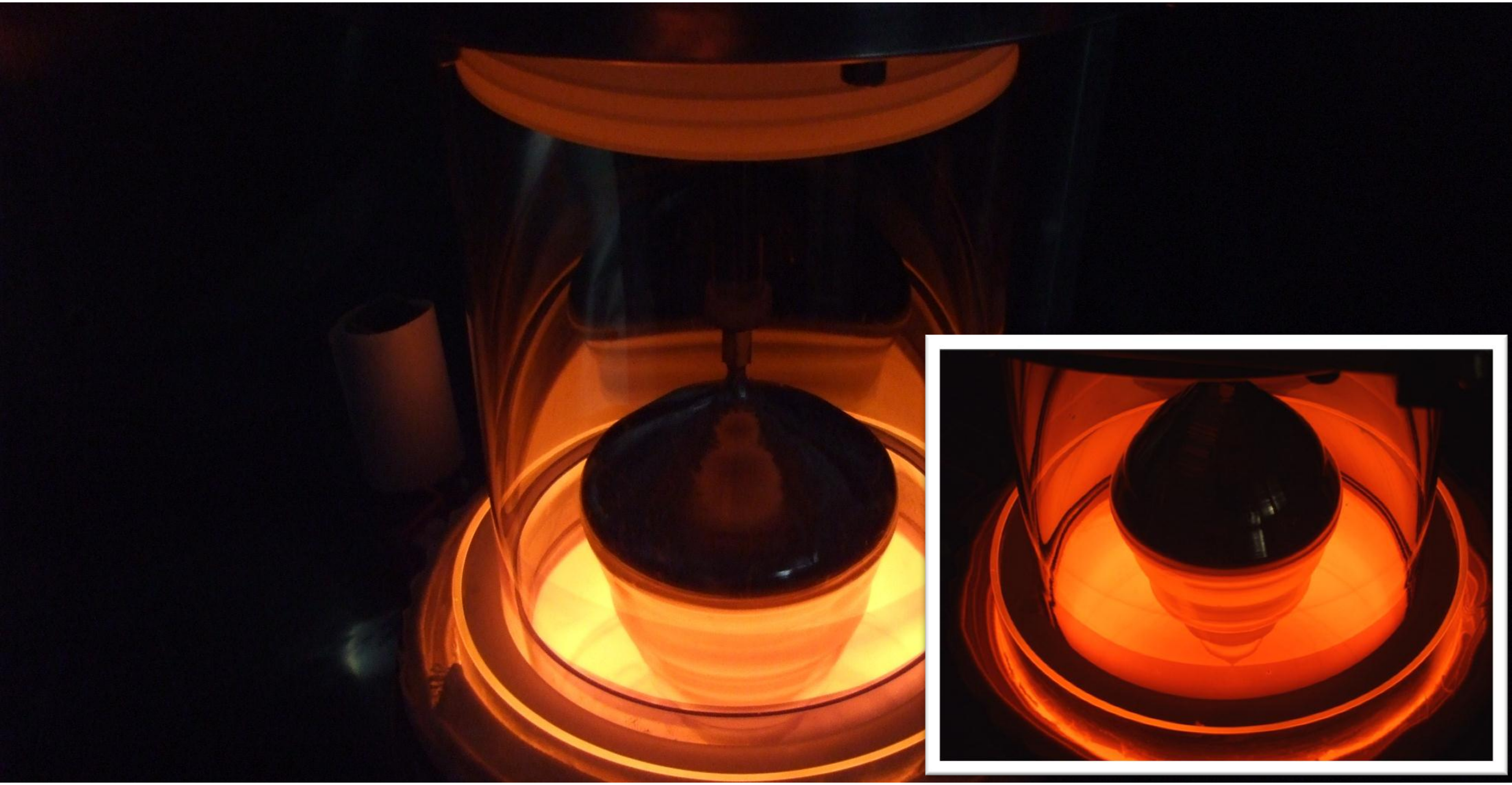


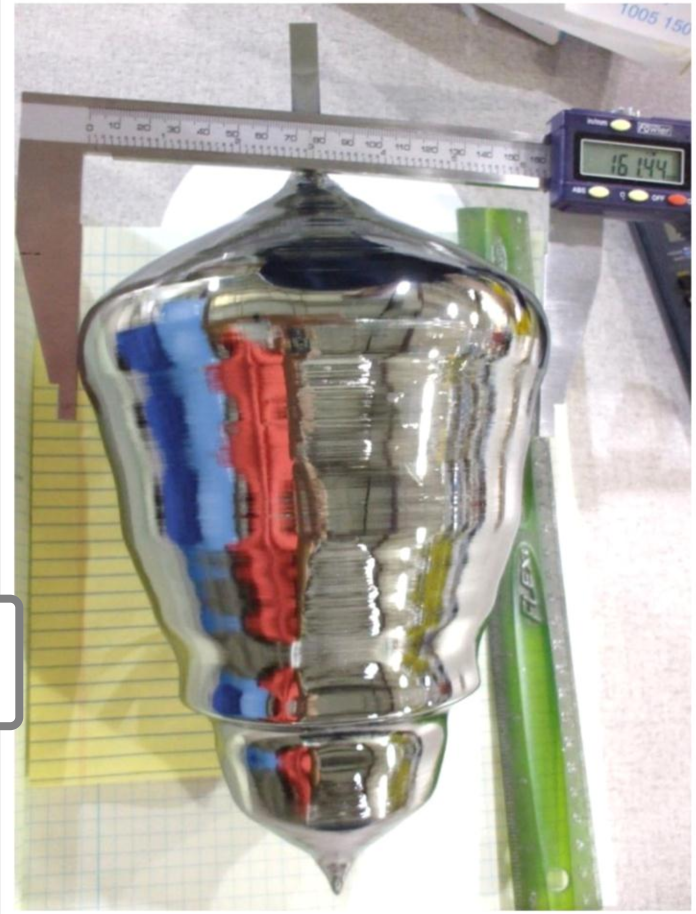
PHDs Co.





PHDs Co.





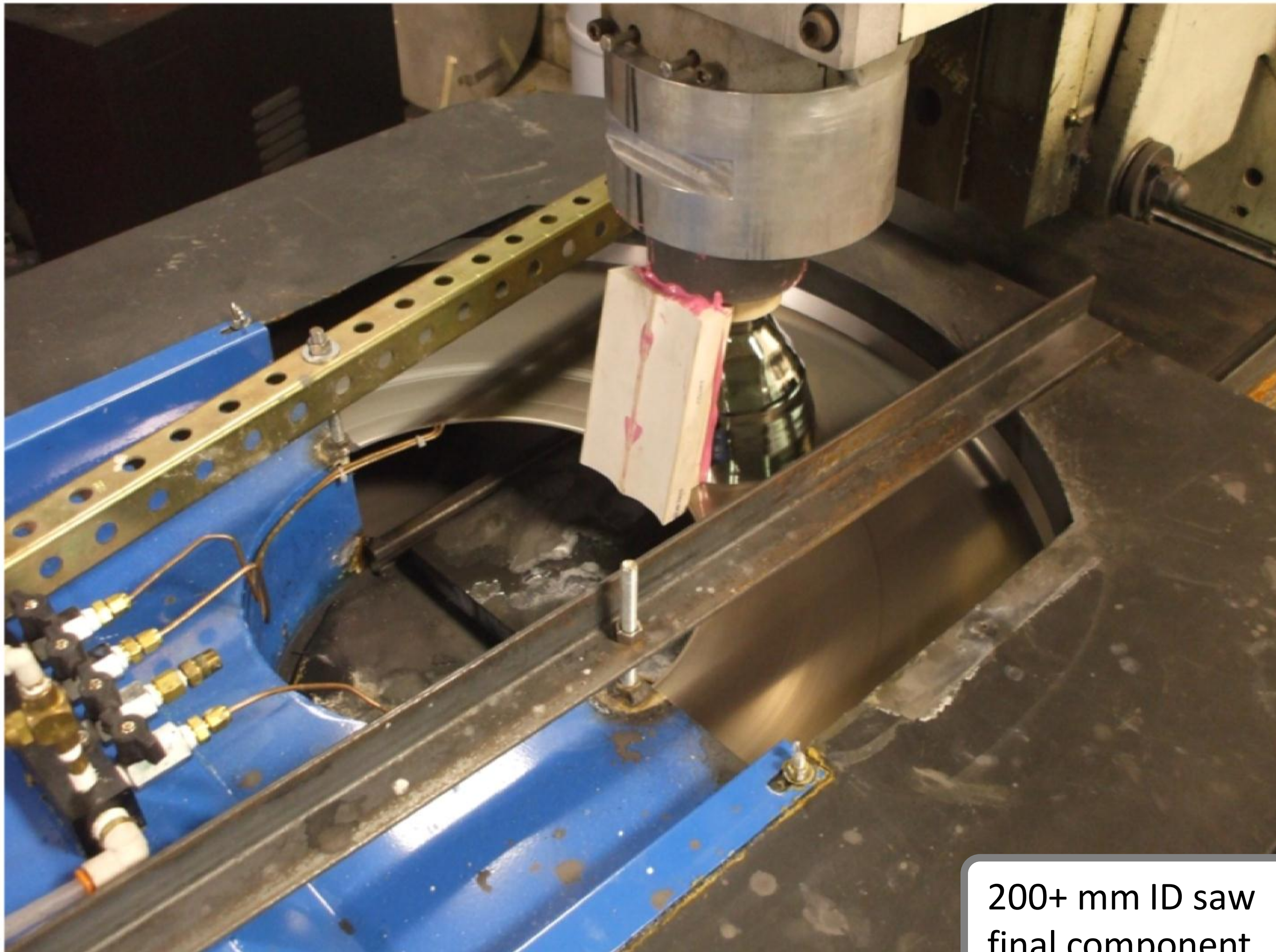
161.4 mm
max sho

6 cm of length
> 140 mm dia.

13,659 g

→ 140-mm diameter selected for the next standard sized detector (cryostat etc)

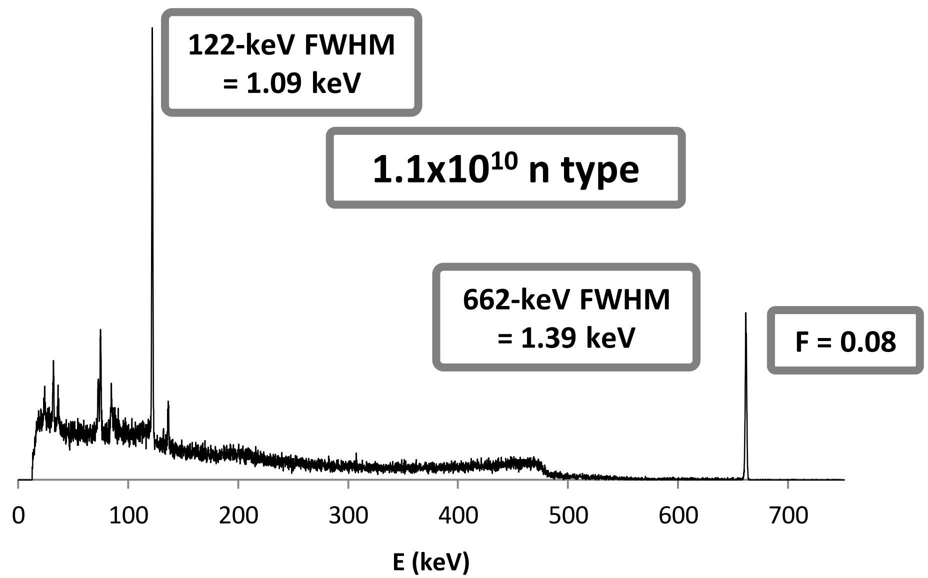
Slicing

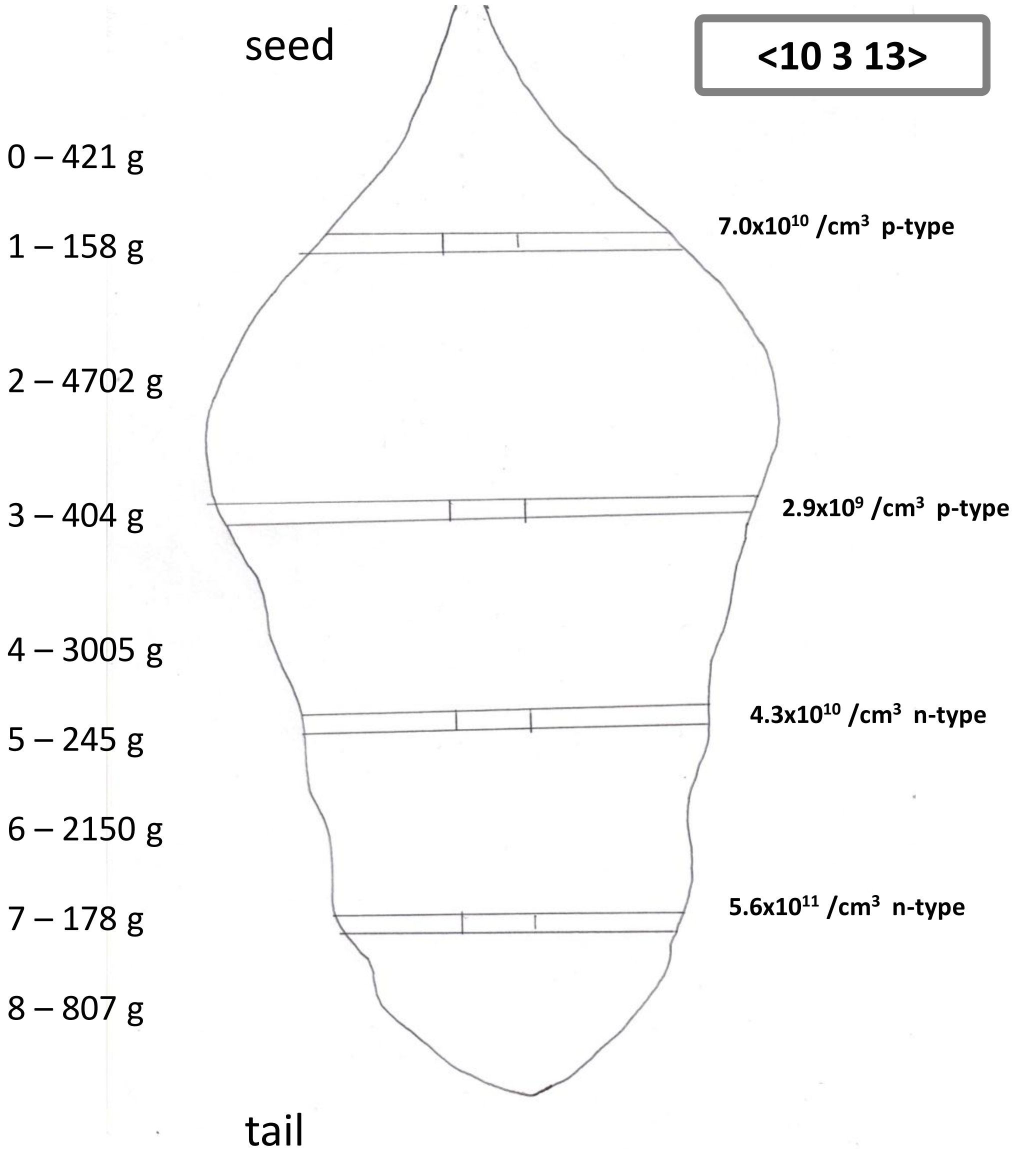


200+ mm ID saw
final component
Inspired by the
successful crystals

Crystal Evaluation

PHDs Co.



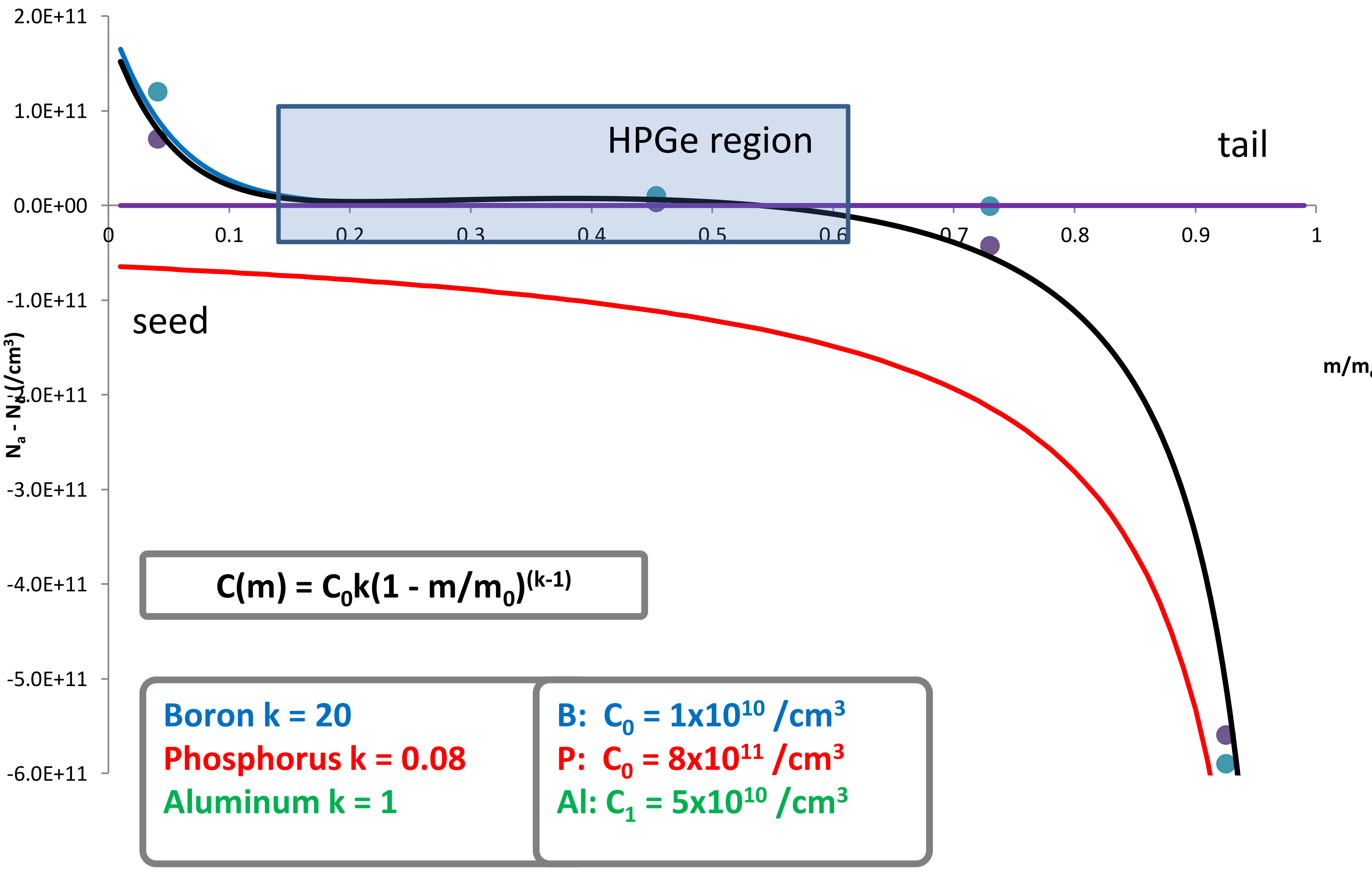


<10 3 13>

- Mass of each slice
- **Net** impurity concentration
- Typeness

$$C(m) = C_0k(1 - m/m_0)^{(k-1)}$$

Boron k = 20
Phosphorus k = 0.08
Aluminum k = 1



2.0E+11
1.0E+11
0.0E+00
-1.0E+11
-2.0E+11
-3.0E+11
-4.0E+11
-5.0E+11
-6.0E+11
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
$N_a - N_d$ (/cm^3)
m/m$_o$
HPGe region
tail
seed
$C(m) = C_0k(1 - m/m_0)^{(k-1)}$
Boron k = 20
Phosphorus k = 0.08
Aluminum k = 1
B: $C_0 = 1x10^{10}$ /cm^3
P: $C_0 = 8x10^{11}$ /cm^3
Al: $C_1 = 5x10^{10}$ /cm^3