

Modular Planar Germanium (MPGe) Detector Systems for High Resolution Gamma-ray Spectroscopy and Tracking Arrays

DE-SC0009639

2/19/2013-4/14/2017 (1-yr NCE)

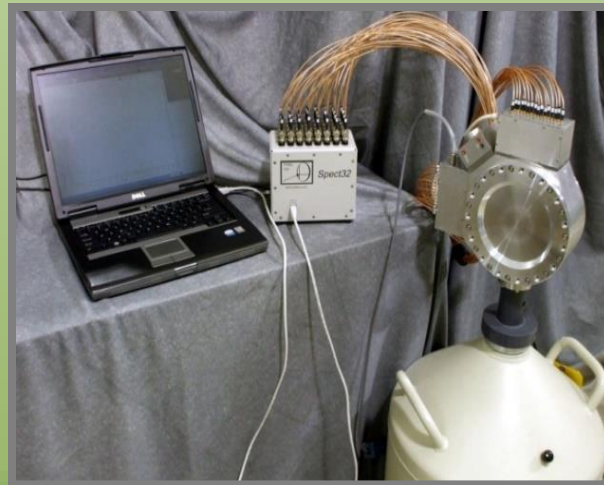
Ethan Hull PI , PHDS Co.

A collaboration with C.J. (Kim) Lister at U. Mass Lowell

- **PHDS Co. Introduction**
- **MPGe Concept**
- **MPGe Evolution**
 - **New Successful prototype**
- **MPGe**
 - **Dramatic Detection Implications**

Introduction to PHDS Co.

- Est. Fall 2004 – Nuclear and Solid State Physics Origin
 - History: Custom Nuclear-Physics Detectors
 - Recently: Modular HPGe Systems
- Small Company, Lean-Organic Growth Model
- Complete Germanium Detector Manufacturing and R&D
 - Concept Design
 - Crystal Growth
 - Detector Fabrication
 - System Integration
 - Software application
 - Sales & Service



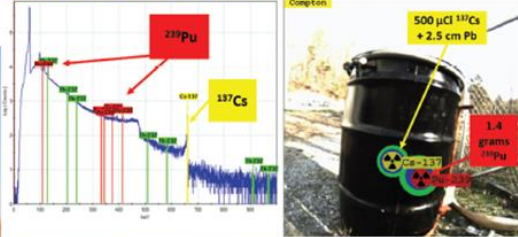
Make an Impact with Imaging Germanium Technology

GeGI[®]

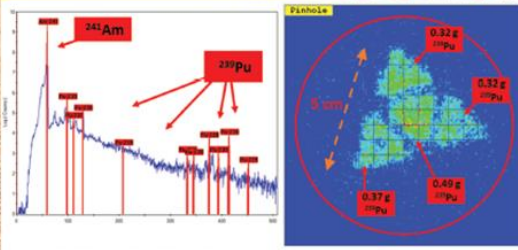
RAD NUC STANDOFF DETECTOR
Locate • Identify • Quantify



Find the Source



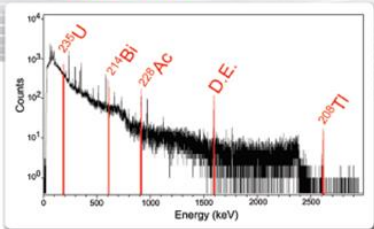
Understand the Source



Wide angle camera captures the field of view

CBRNE Training Exercise Results

High Resolution Spectroscopy and Automatic Identification



Applications

- Military and Civilian CBRNE Operations
- Nuclear Safeguards
- Nuclear Security
- Special Nuclear Materials Proven

Specifications

Dimensions: 12 in x 9 in x 6 in
 Weight: 28 lbs (3.1 lbs NiMH battery)
 Battery life: 8-10 hours (external Li ion battery packs) 1 hour (internal battery)
 Power supply: 100-240 VAC, 50-60 Hz
 User maintenance: None

Energy resolution: FWHM < 2.1 keV (0.3 %) at 662 keV
 Gamma-ray Compton imaging field of view: 4π (360°)
 Optical (camera) field of view: 2π (185°)
 Pinhole imaging field of view: 60° cone

Sensitivity: 10-µCi ¹³⁷Cs at 1 meter (3.3 µR/hr, 33 nSv/hr)
 Detection and ID time (662 keV) (8σ): 3.7 sec ± 1.0 sec
 Location (Compton image) time: 30 sec ± 13 sec

Dose-rate capacity: 8.5 kcps (10% Dead time) in 1.5 mR/hr ⁶⁰Co
 Energy range: 40 keV – 3 MeV

Imaging energy range:
 Pinhole (2.54-cm thick Pb 60°) : 40 keV – 662 keV
 Compton: 140 keV – 3 MeV

Isotope library (400 Isotopes): Auto detect and/or user specified
 Isotope Identification: 35 frequently encountered isotopes
 Detector (Ge crystal) dimensions: 90-mm diameter, 10-mm thick

Active detector volume: 55 cm³
 Active detector area: 55 cm²
 Cool-down time: 2.5 hours
 Start-up time (cold): 2 minutes

Included: Tablet, pelican case, power supply w/charger

Rolling Pinhole Imaging Tripod
 1-in thick Pb
 60-degree Field of View

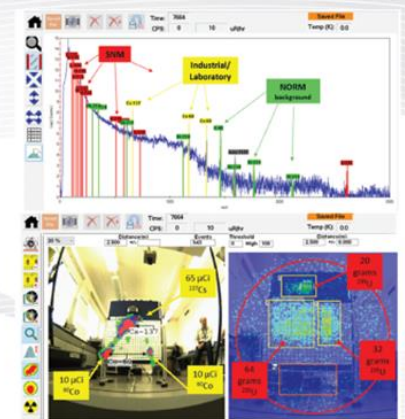


Features

- Standoff Location Detection Identification
- Distance Range (10 cm - 50+ meters)
- Automatically specifies SNM, NORM, IND, MED
- Germanium gamma-ray spectroscopy
- Full 360° Standoff Visualization (Compton)
- ²³⁸U (186 keV) ²³⁹Pu (375 keV, 414 keV)
- User-friendly auto tablet or laptop operation
- Full session save and reload capability
- Named-pipe data acquisition and system control
- Full data-stream access
- Wireless capable
- TwistLock mil-spec power connector
- Long-lived mechanical cooler (5 years +)
- Reachback file: ANSI N42.42 format

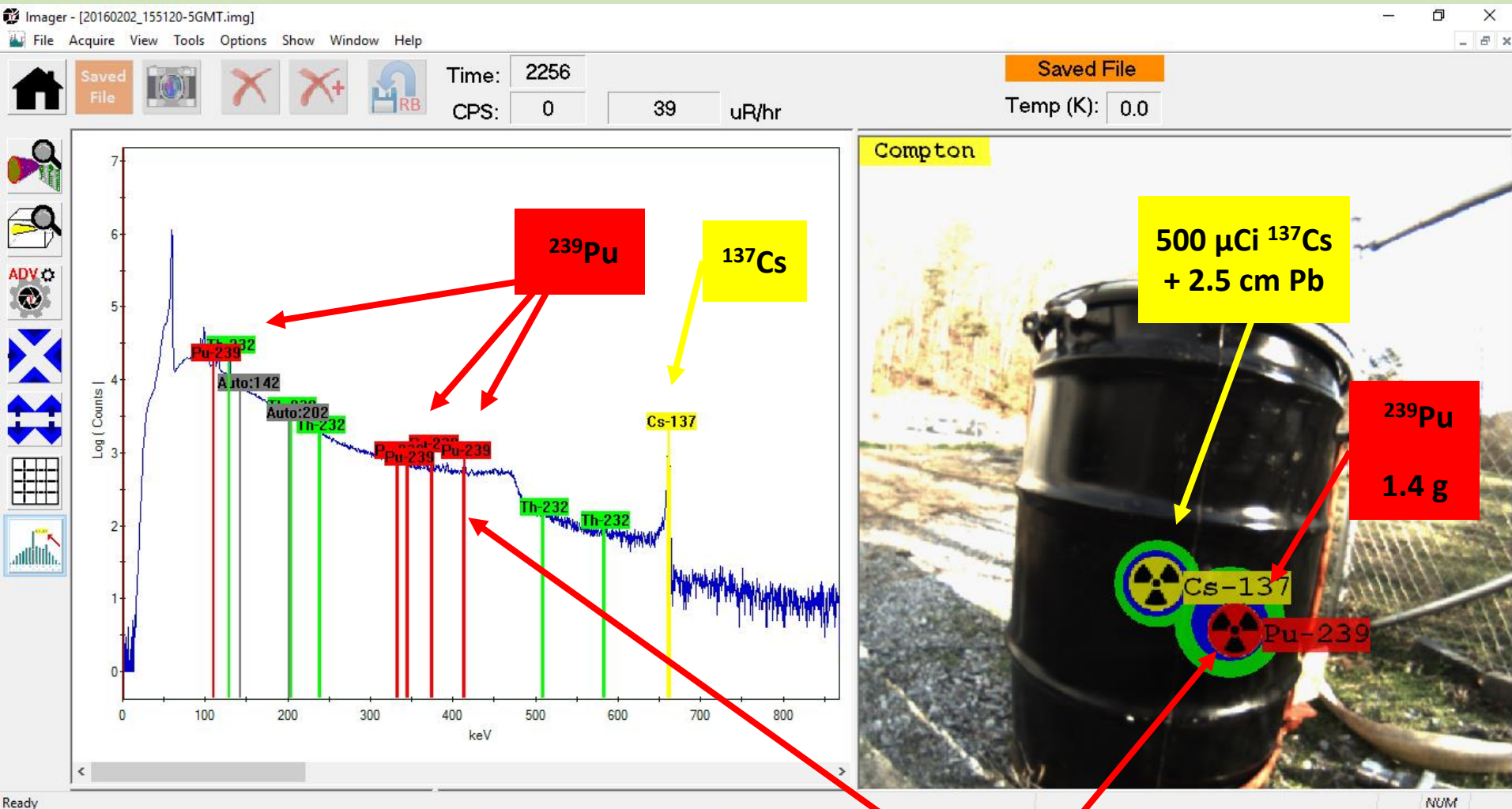


External Li ion Battery Pack



CBRNE Team Training

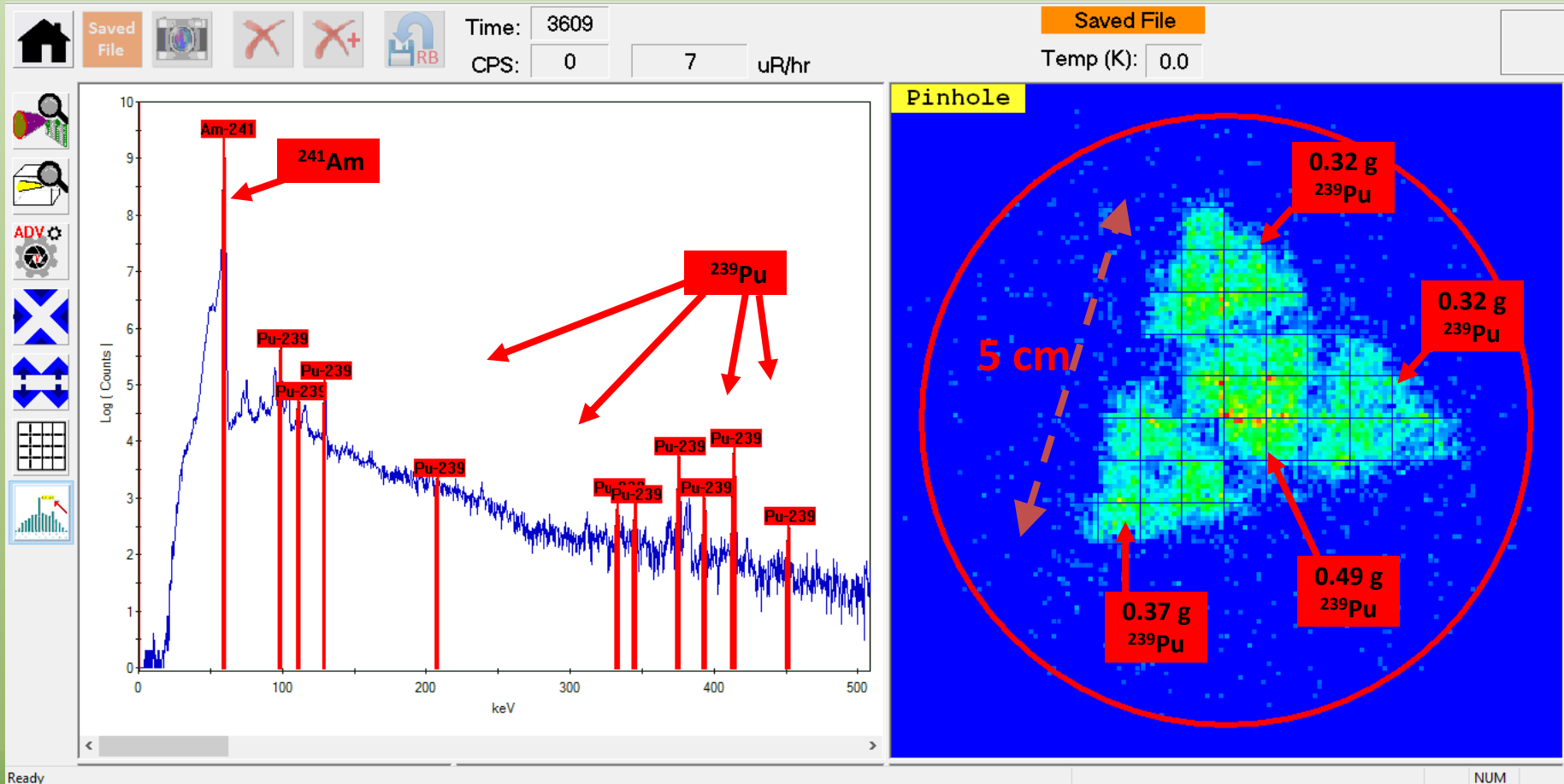
^{239}Pu ID and Location



Energy resolution is very important here
This could not be done without imaging

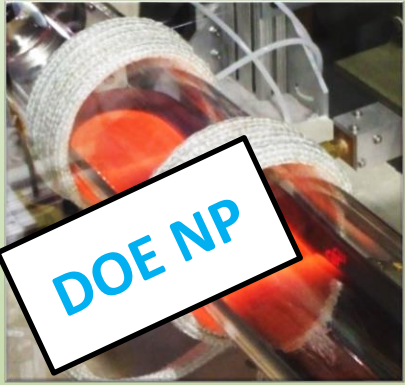
Image detail

Target: Shaped ^{239}Pu Sources



**10,000 ft² Manufacturing
and R&D Facility in
Knoxville, TN**





DOE NP

Zone Refine



DOE NP

Growth



DOE NP

Analysis



Fabrication



Commercial

Commercial



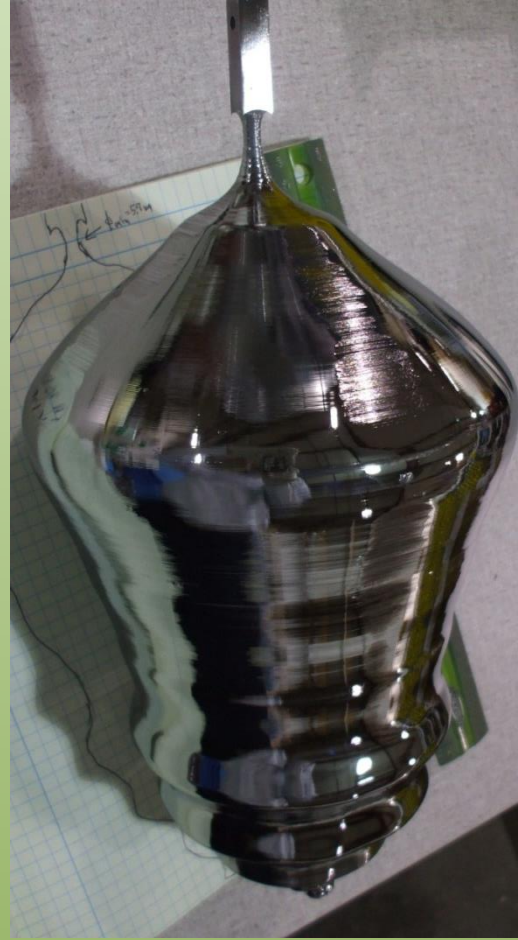
**Integration
Electronics
Imaging**

Commercial



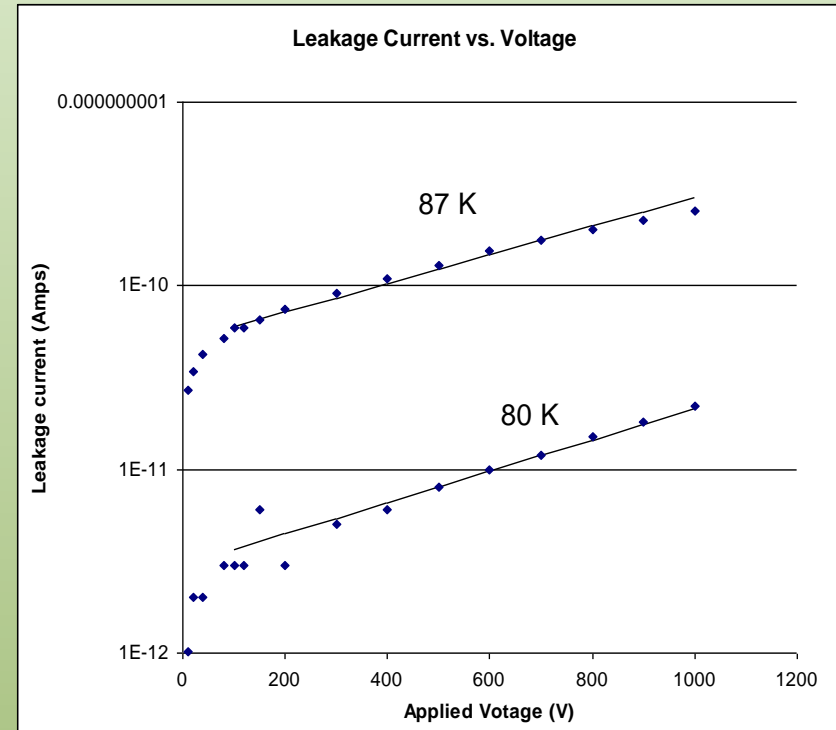
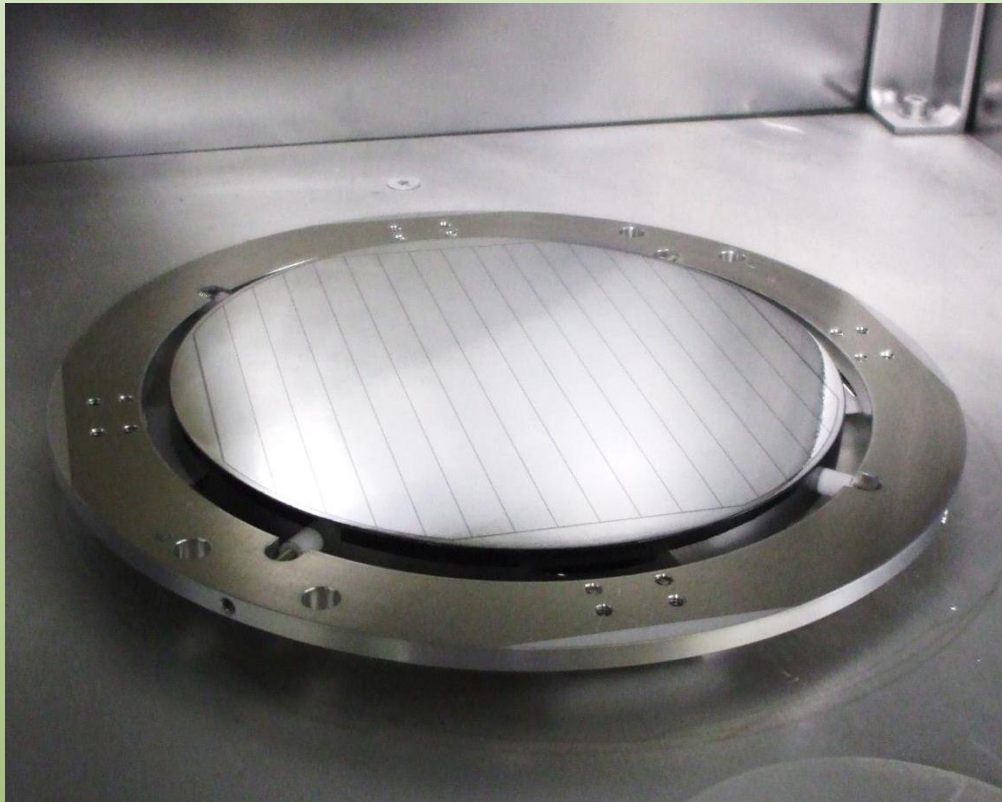
Cryogenics

Large diameter/volume HPGe Crystals DOE NP Development



Segmented HPGe detector fabrication

DOE NP Developed



Surface contact physics: α Ge, Y, Ag, ...

$$j = j_{\infty} \exp\left(-\left\{\phi - \left[\left(\epsilon_0 \epsilon_{\text{Ge}} / N_f\right)^{1/2} (V + V_{\text{depl}}) / d\right] \right\} / k_B T\right)$$

- Semiconductor Barriers
 - Segmentation
 - Function at ~ 77 K
- Non-standard semi

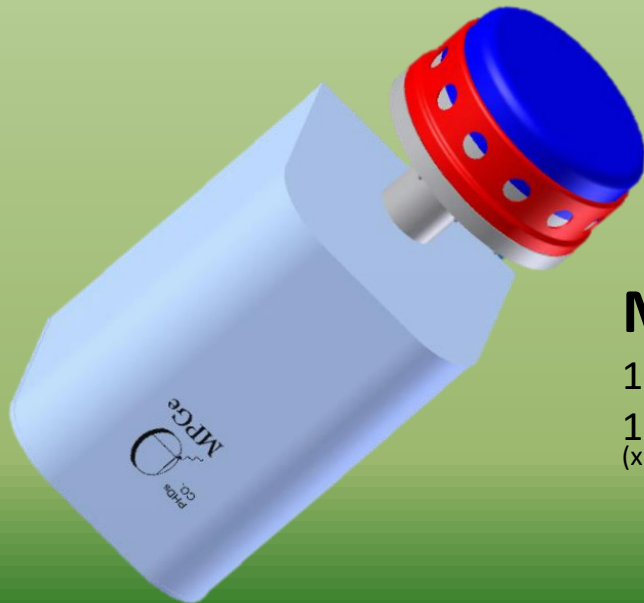
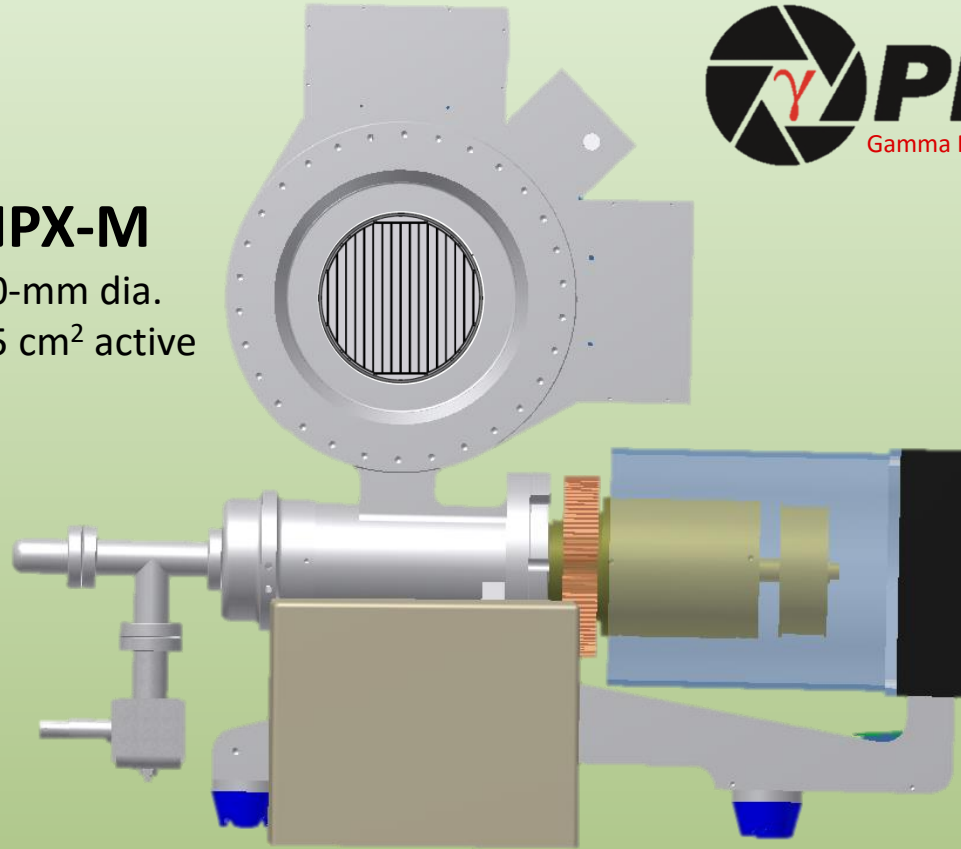
E.L Hull, R.H. Pehl, "Amorphous germanium contacts on germanium detectors," Nuclear Instruments and Methods A, **538**, Issues 1-3, (2005), Pages 651-656.

Hull EL, R.H. Pehl, J.R. Lathrop, B.S. Suttle, "Yttrium hole-barrier contacts for germanium semiconductor detectors." Nucl. Instr. and Meth. A 626–627 (2011) p. 39–42 (2011), doi: 10.1016 / j.nima.2010.10.029.



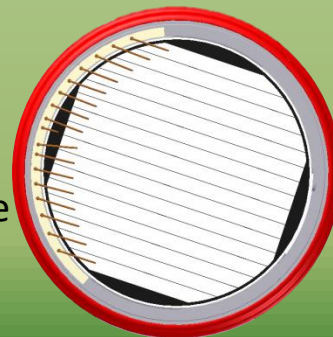
NPX-M

90-mm dia.
55 cm² active



MPGe

140-mm dia.
133 cm² active
(x2.4)



**Less hardware
around the detector
Greater detector
area**



MPGe

4-Detector Array

14.7 cm face to face

2π solid angle coverage

6 ft. tall

Close proximity

→ Compact assembly!

- System design and fabrication challenges

Higher luminosity physics

10 particle nA x100 → 1 p uA

→ More radiation damage!

→ 5×10^9 /cm² 2 weeks 40 kcps (10 cm 1 mg/cm² Pb)

- Lower Operating Temperature
- Trap Correction
- Annealing (High temperature)

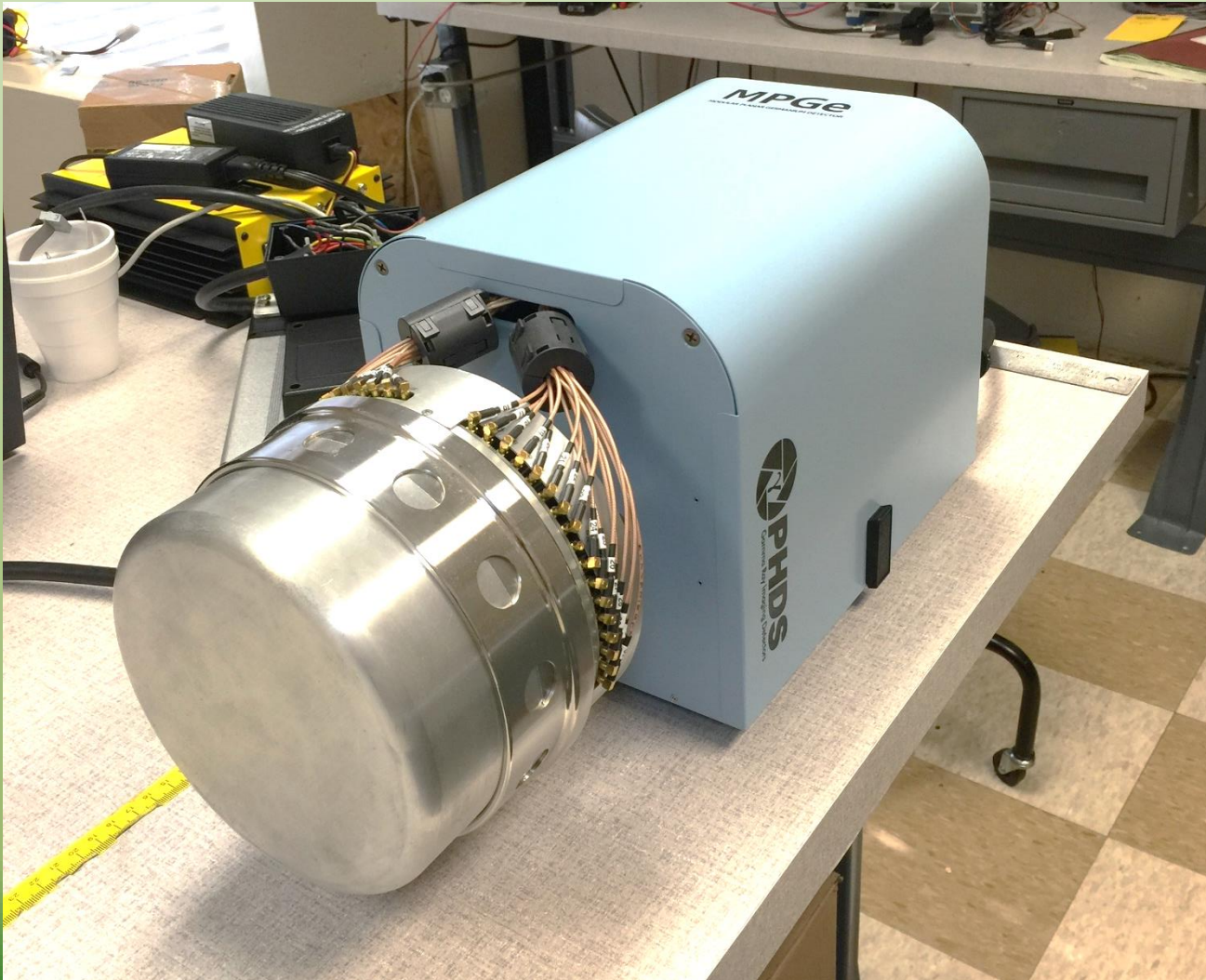
MPGe System Design



Detector 140 mm
diameter

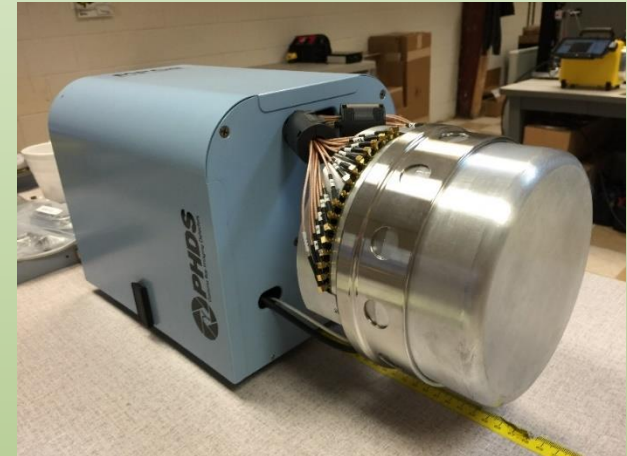
The first MPGe 140-mm diameter planar detector is functional !!

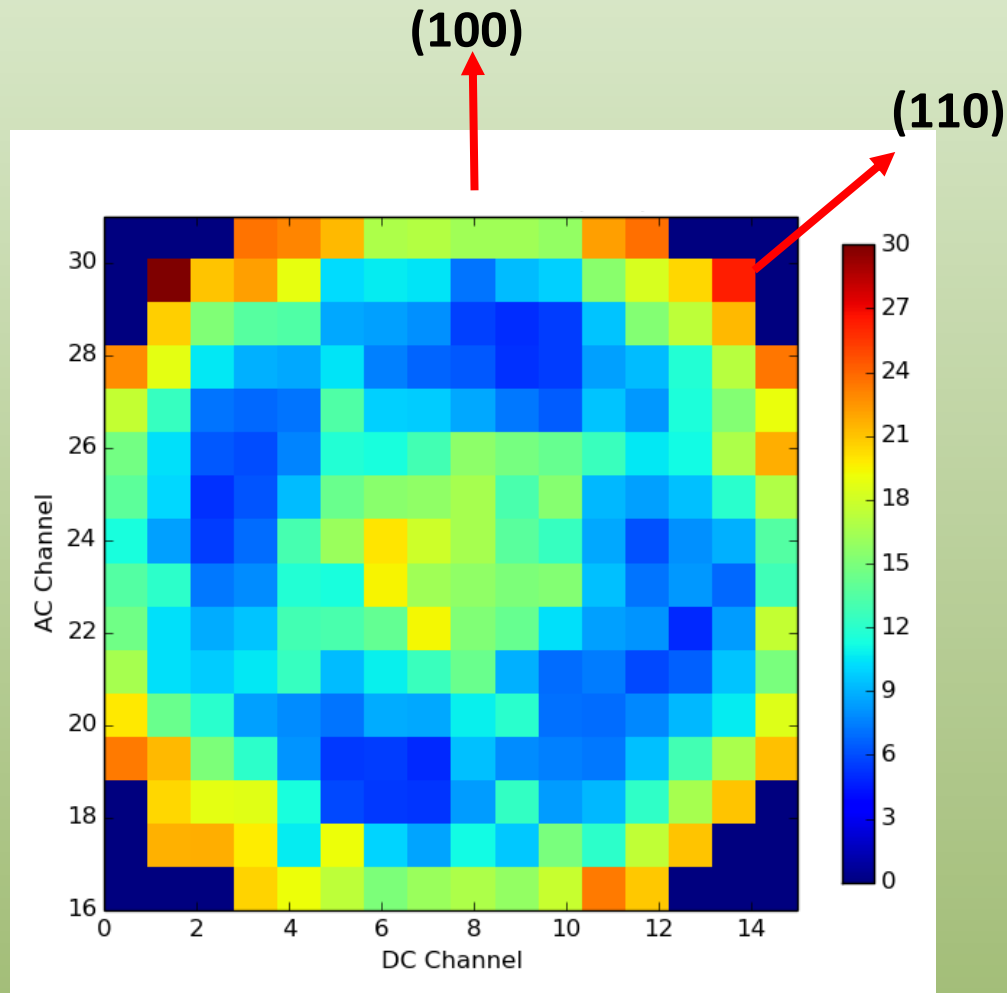
As shown here, the system is fully integrated with control electronics and readout



MPGe Prototype Basic Properties

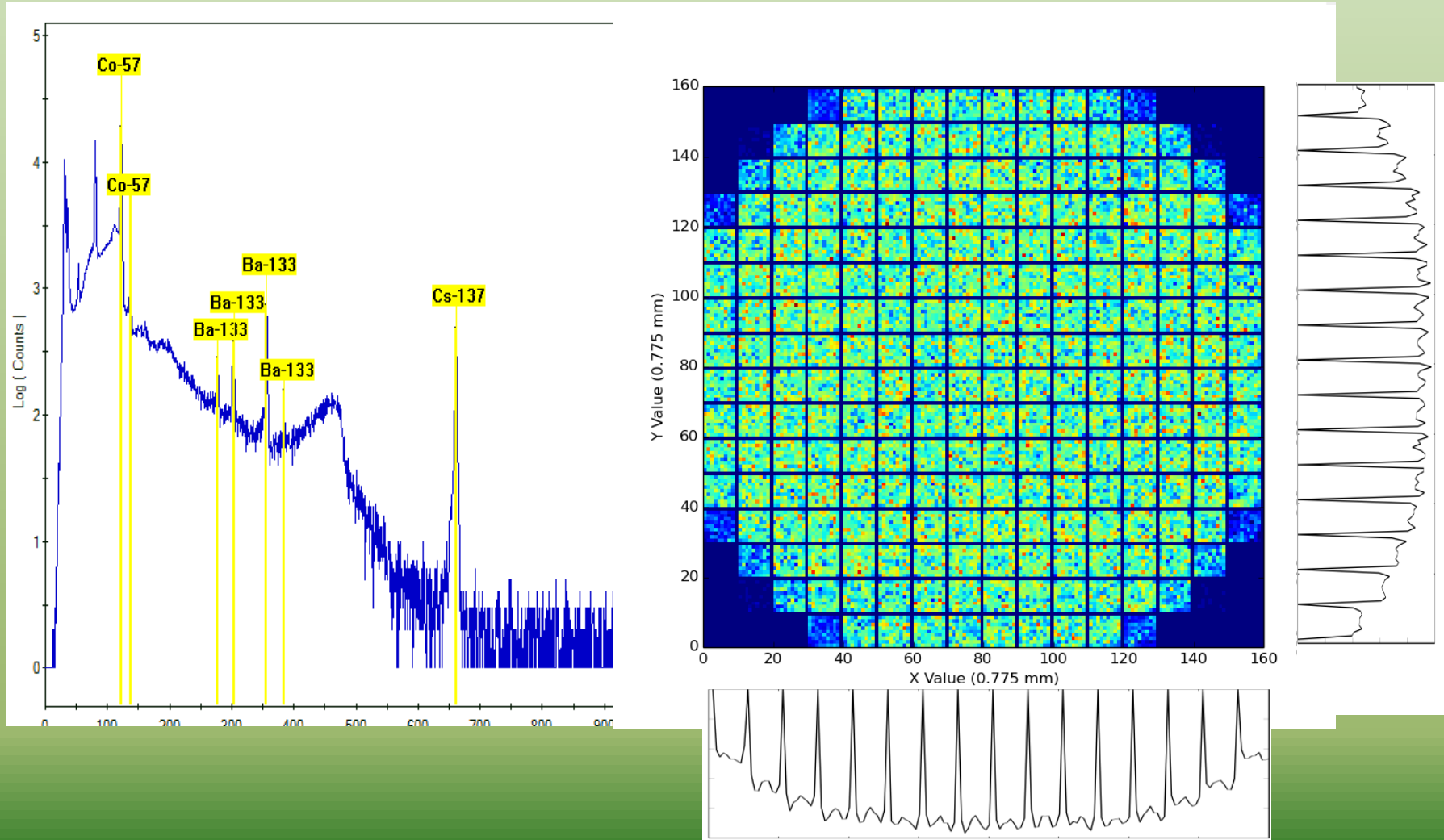
- MPGe assembled and fully functioning
- Detector
 - 140 mm dia. x 10 mm thick
 - (100) HPGe crystal
 - $V_{\text{dep}} = -350 \text{ V}$
- Segmentation
 - 16 x 16 orthogonal strips
 - Pixel pitch = 7.75 mm
 - Gap width = 0.125 mm
- Cryogenics
 - $T = 58 - 81 \text{ K}$





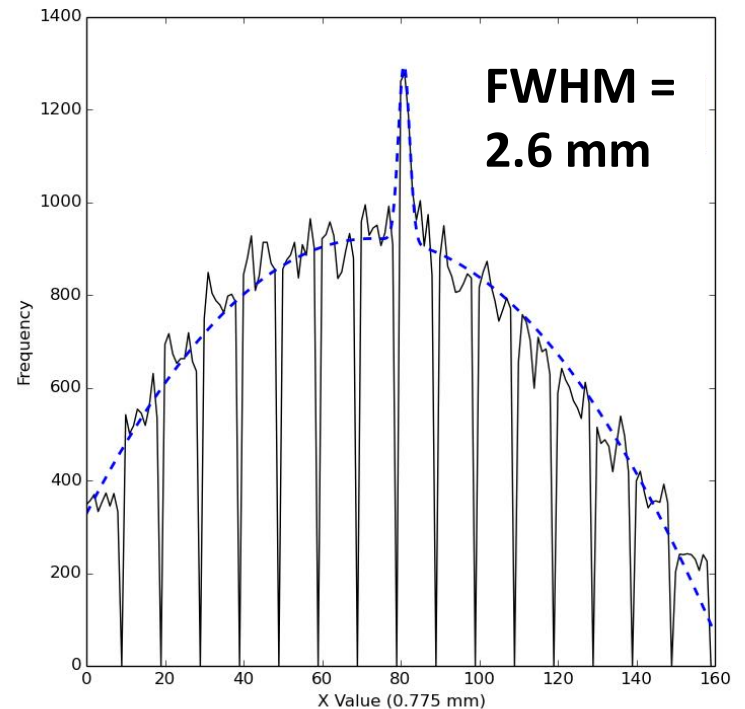
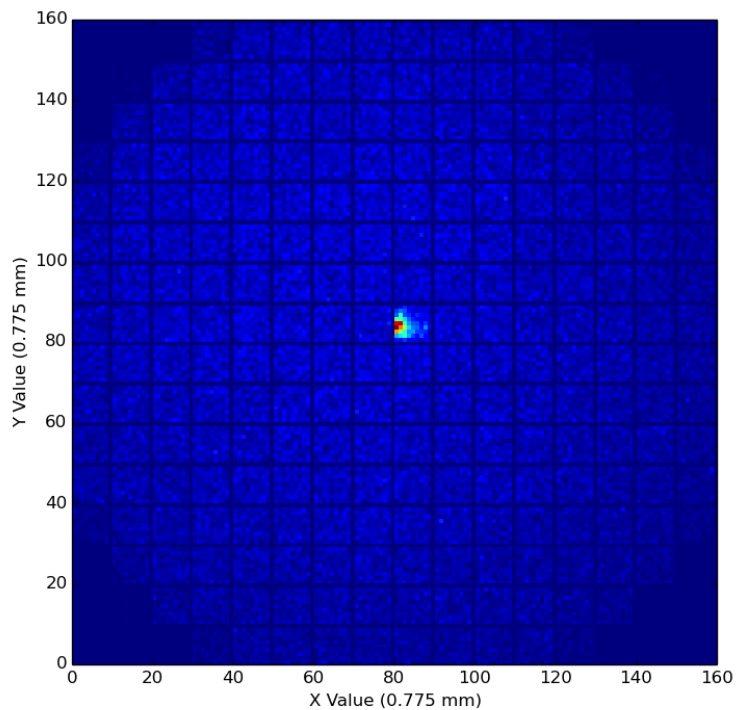
**(100) HPGe crystal
(into page)**

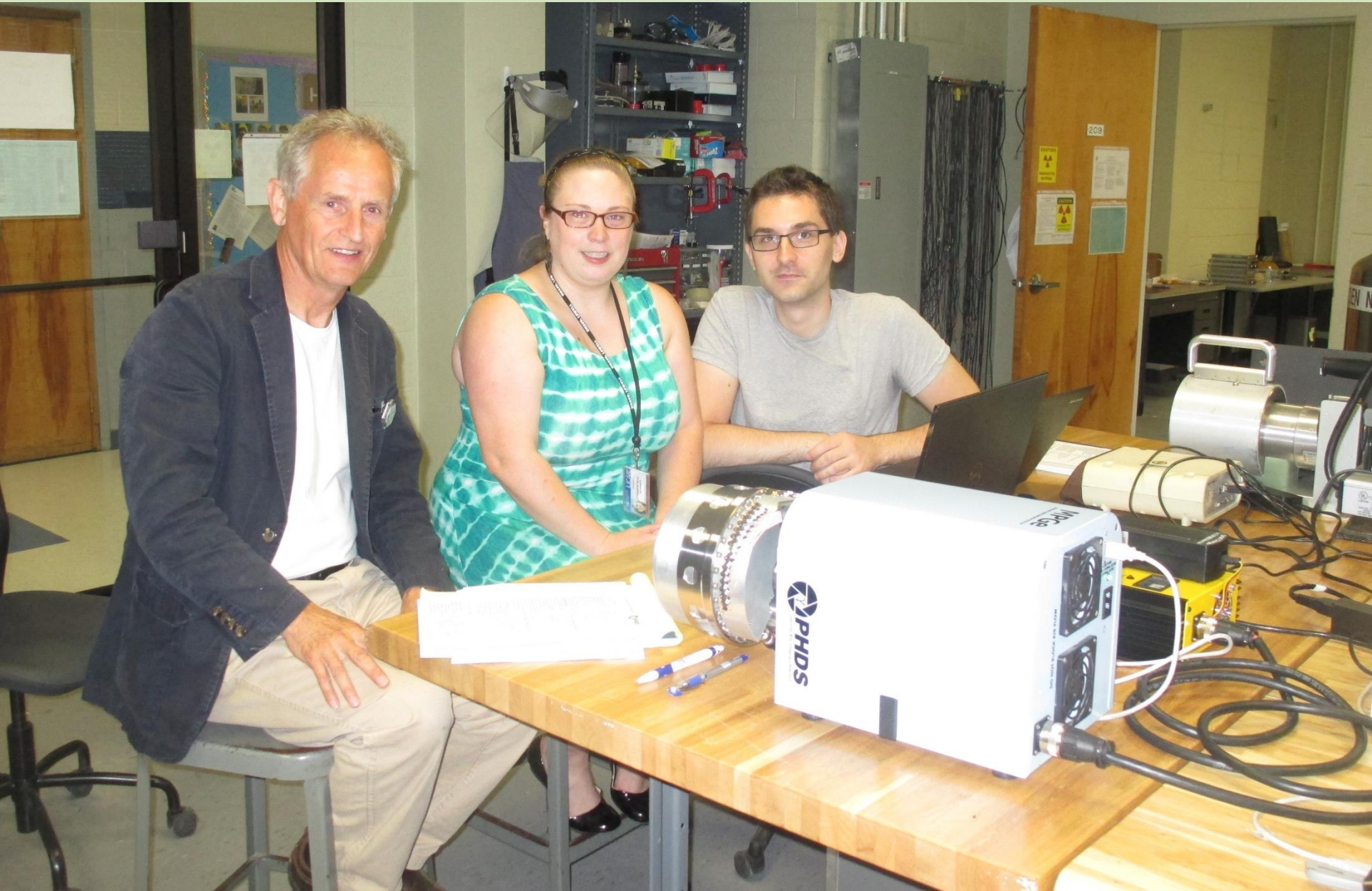
Flood Image – Parametric Spatial Interpolation



^{57}Co “Beam” – Parametric Interpolation

- ^{57}Co source
- 1/8” thick Pb collimator
- 0.5 mm straight pinhole (2.5 mm x, 3.4 mm y)
- Spatial resolution FWHM \sim 2.6 mm at 122 keV

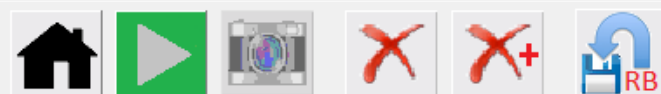




Depleted Uranium measurement



File Acquire View Tools Options Show Window Help



Time: 39548

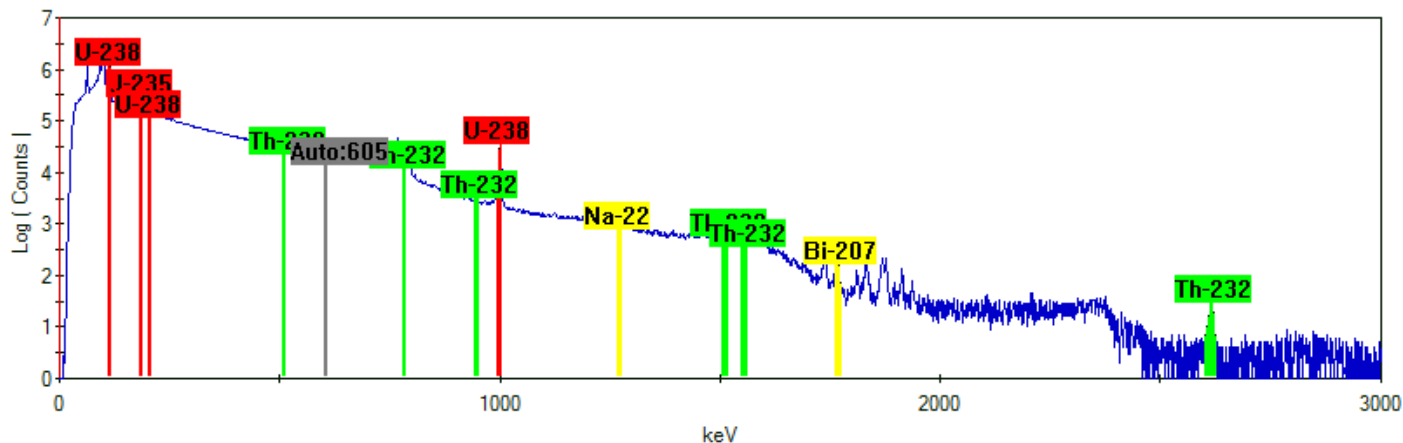
U-235 Detected: DEPLETED

Saved File

CPS: 0

198 uR/hr

Temp (K): 0.0



Detectors

Find Gammas Pixel Total

Rebin 2

Eng Spec Show all

Ave Spec F/Eng

Fast Chan Fpred-Fsucc

Delta T Waveforms

Peak info

Centroid:

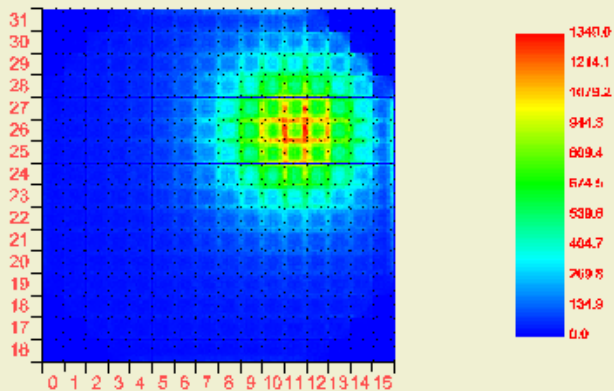
FWHM:

FWTM:

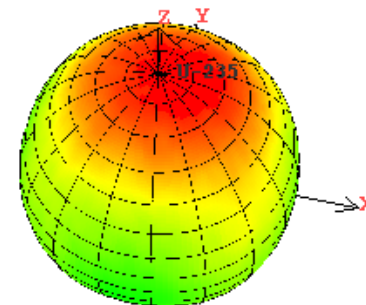
Gross area:

Net area:

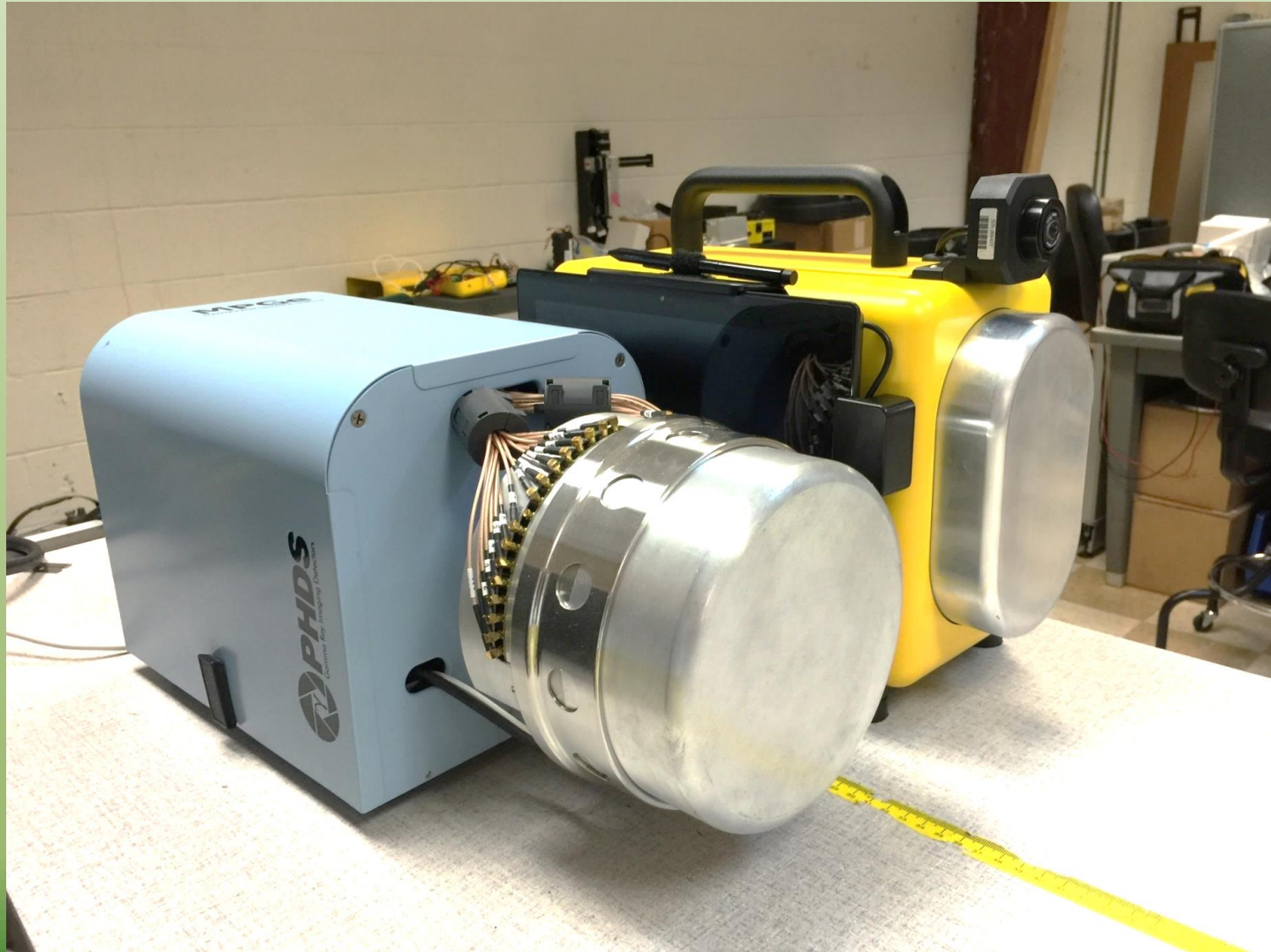
Planar

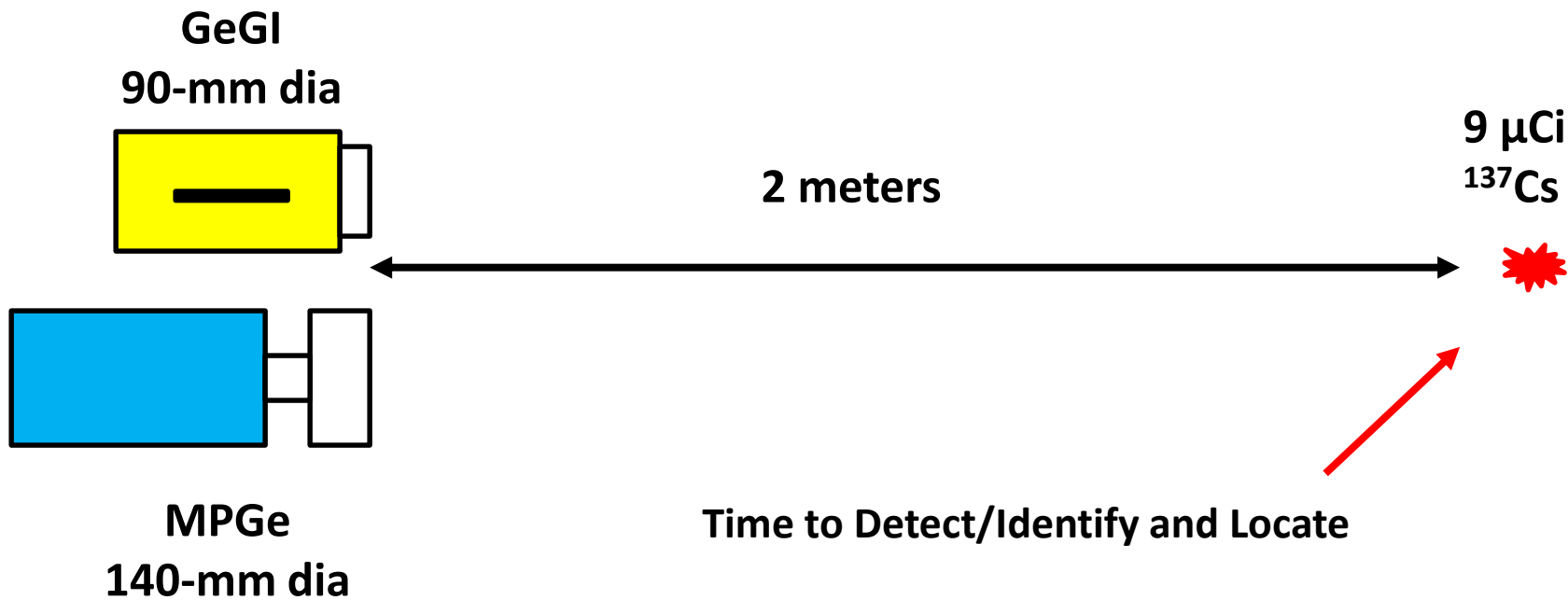


Scientific

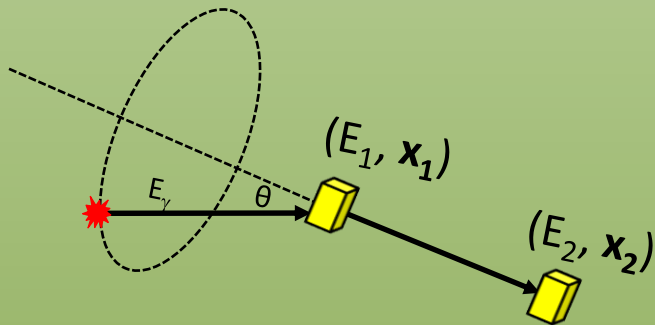


**MPGe vs. GeGI – Comparison at PHDS Co.
Implications for:
Detection, Identification, and Location**

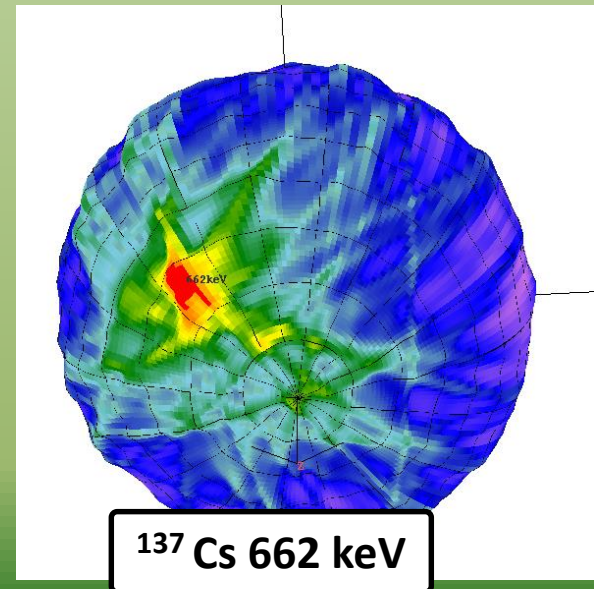
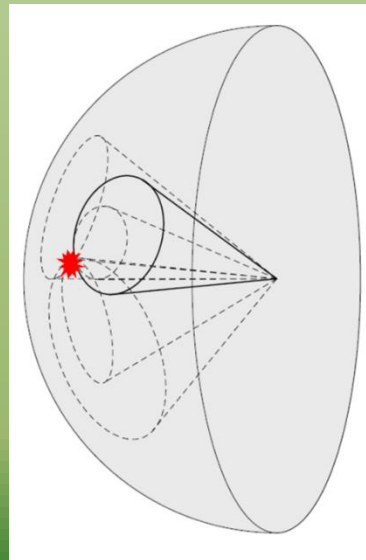




Compton kinematic γ -ray imaging (γ -ray tracking)⁻¹

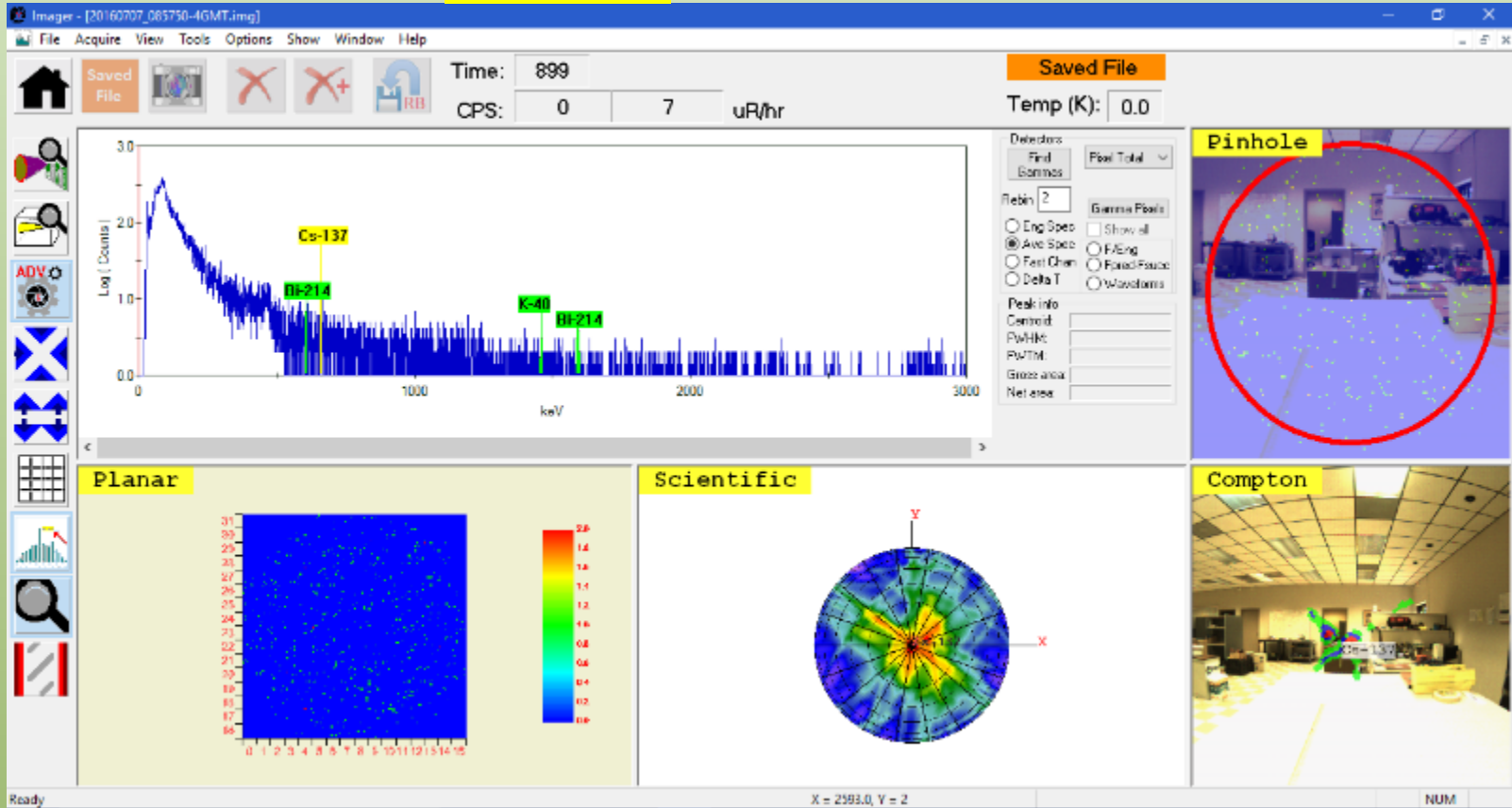


$$\cos \theta = 1 - m_e c^2 \left(\frac{E_1}{E_2(E_1 + E_2)} \right)$$



GeGI
90-mm dia

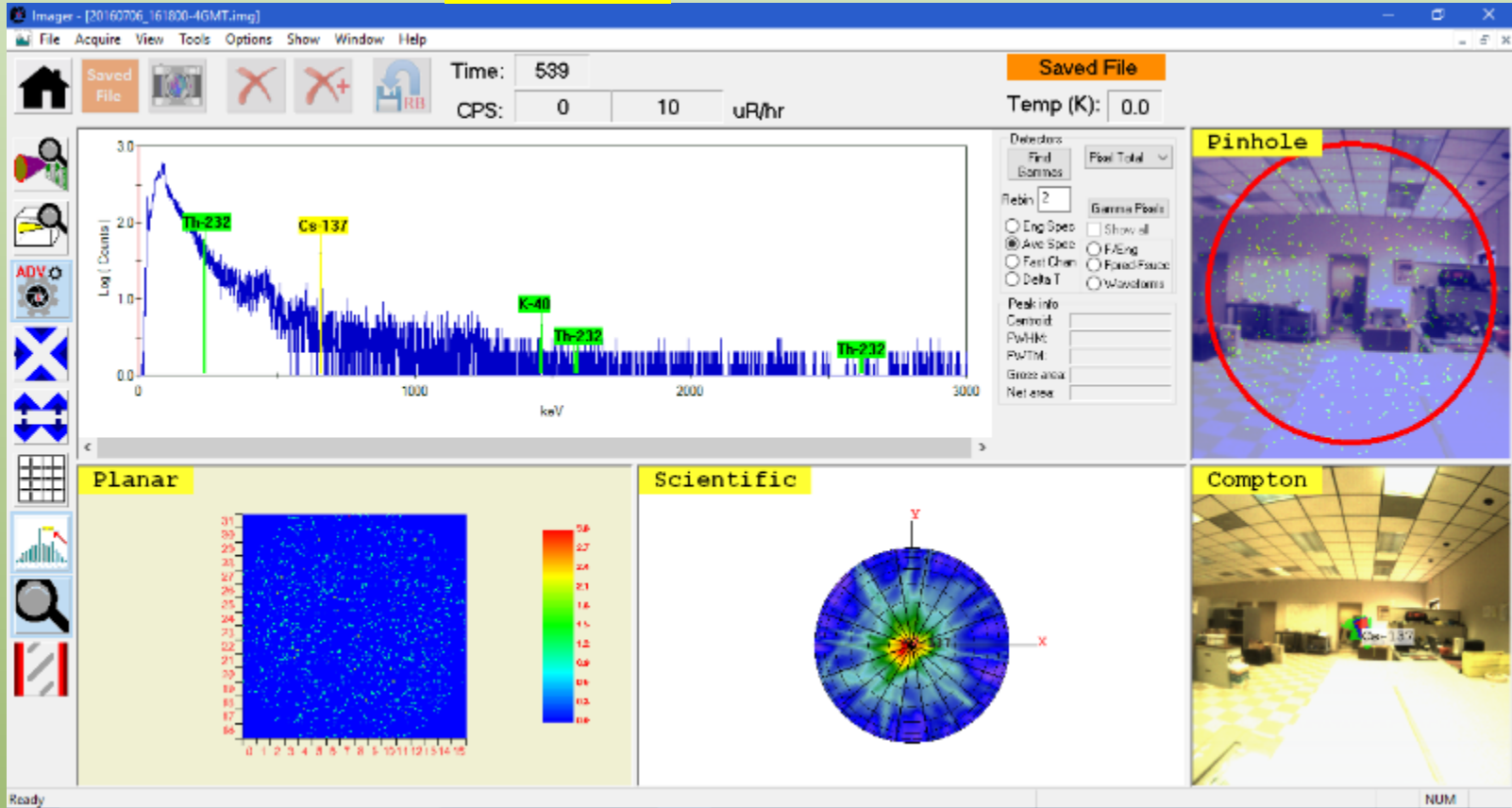
30 sec ID



420 sec Locate

MPGe
140-mm dia

10 sec ID



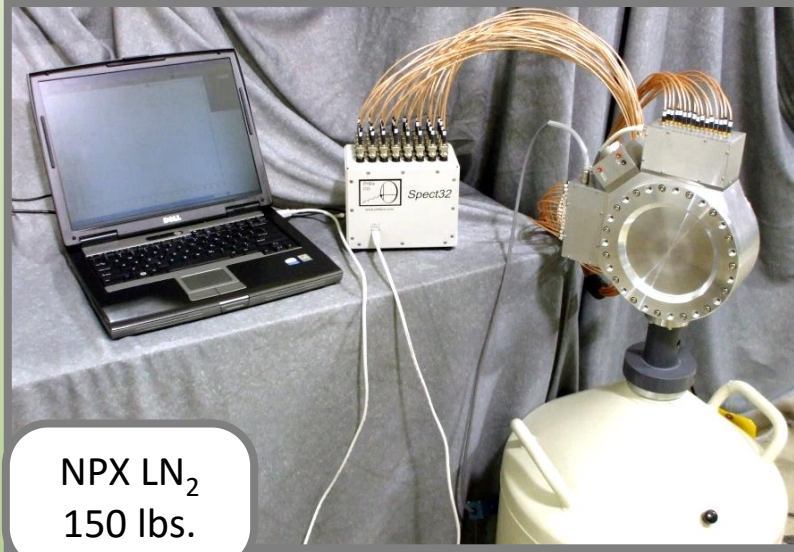
190 sec Locate



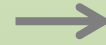
	GeGI (90-mm dia)	MPGe (140 mm dia)
Time to Detect (6σ)	30 sec	10 sec
Time to Locate (2σ)	420 sec	190 sec

9 μCi ^{137}Cs at 2 meters

Product / System Evolution



NPX LN₂
150 lbs.



GeGI
28 lbs.



NPX-M
31 lbs.



MPGe x2.4
34 lbs.