Thin-window p-type point-contact germanium detectors for rare particle detection

DE-SC0006348 Ethan Hull PI , PHDS Co.

8/6/2012-8/7/2015

Collaboration with David Radford at ORNL

- PHDS Co.
- Physics challenge: hole-barrier contacts on germanium detectors
- A “thin” contact for low background counting
    - Slow pulses from lithium
    - Material loss of volume
- Development of a new “thin” Ag contact
    - PPC Detector Fabrication
    - **Sputtered Ag and αGe contact alpha particles** – **thickness** !!!!
        - Important insights into contact physics
        - Modifications to fabrication of planar detectors (including GeGI)
- GeGI commercial development

PHDS Co.

3011 Amherst Rd, Knoxville, TN www.phdsco.com

PHDS
Gamma Ray Imaging Detectors

- Est. Fall 2004
- 10 FTEs + 4 Consultants – Technical Origin
  → Business Development
  Branding, marketing, sales,…

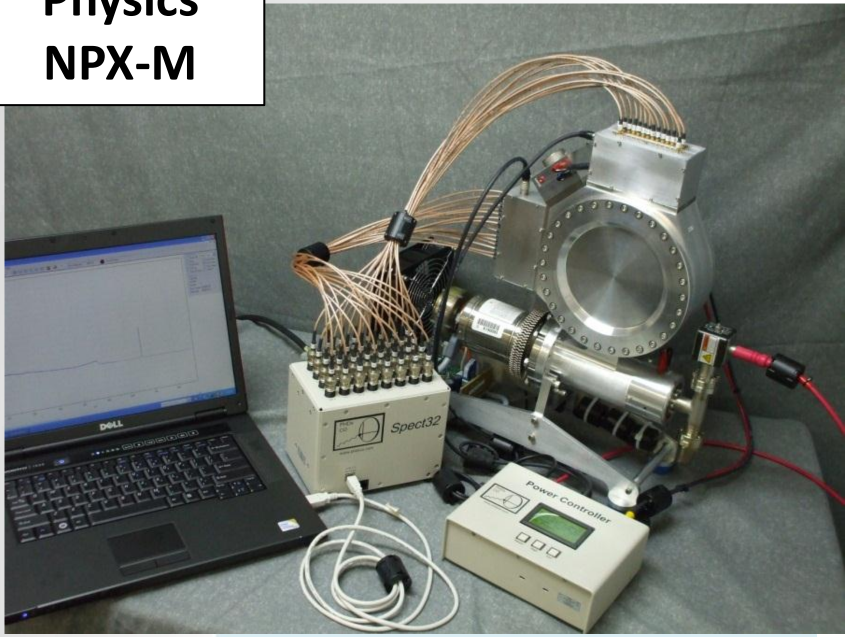
- Complete Germanium Detector Manufacturing
  - Concept
  - Mechanical-Vacuum-Cryogenic Design
  - Germanium Crystal Growth
  - Detector Fabrication
  - System Integration
  - Software application

- PHDs Co. sells germanium detectors
  - Nuclear Physics - **NPX-M** (**N**uclear **P**hysics e**X**perimental)
    - DOE Nuclear Physics support has been basis for tech development
  - Security Applications – **GeGI** (**G**ermanium **G**amma-ray **I**mager)
  - Nuclear Medicine – **GGC** (**G**ermanium **G**amma **C**amera)

Make an Impact with Imaging Germanium Technology

PHDS
Gamma Ray Imaging Detectors

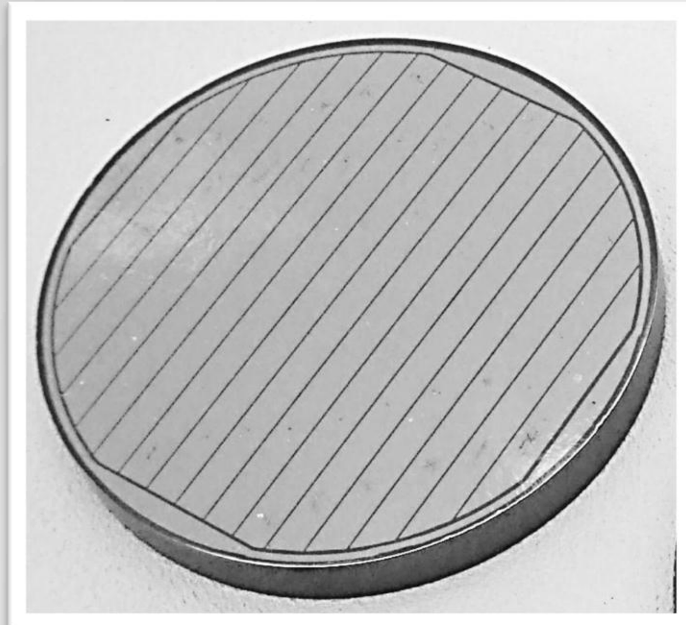
Nuclear Physics NPX-M

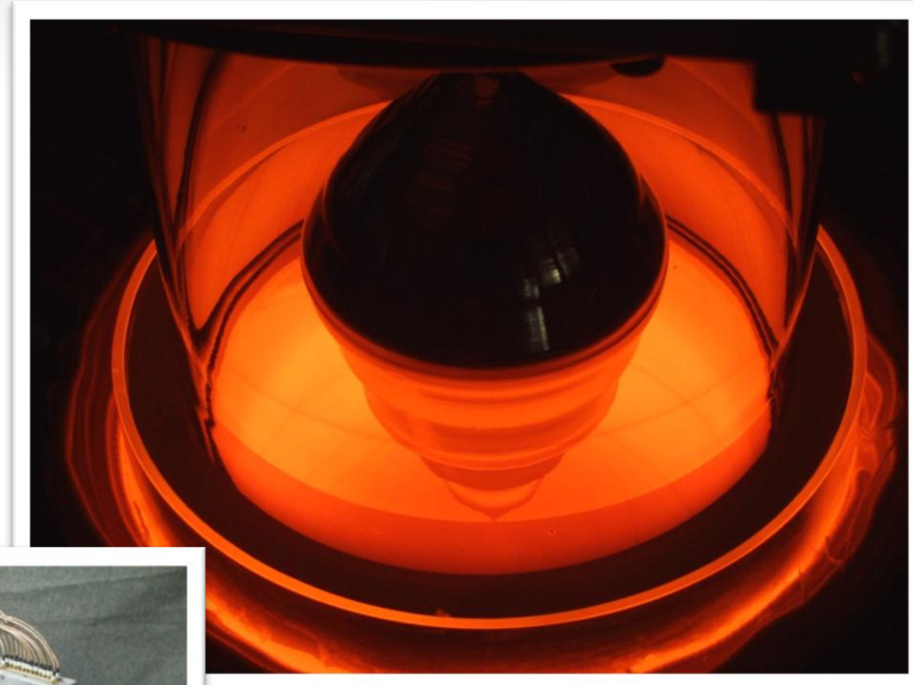


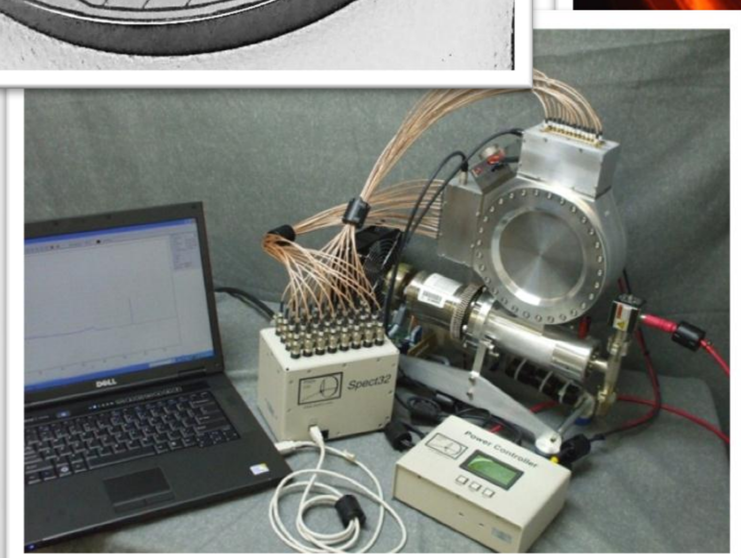
Nuclear Security GeGI

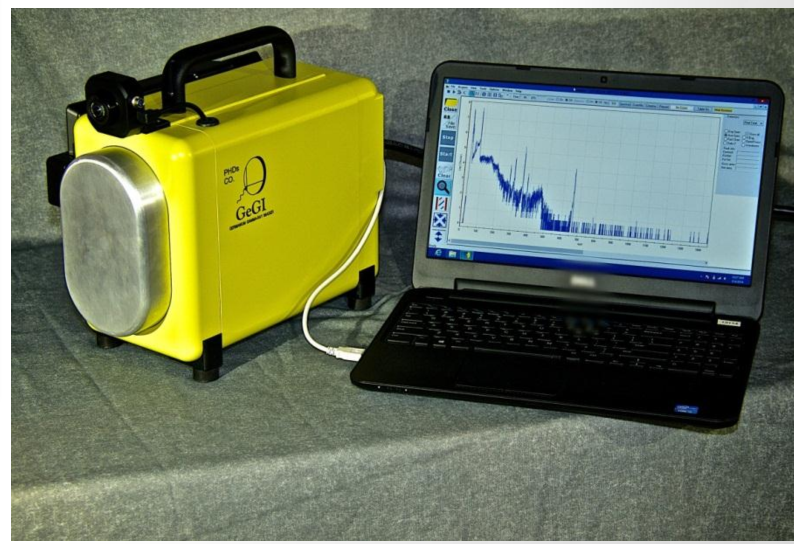
Nuclear Medicine GGC


PHDS
Gamma Ray Imaging Detectors









DOE Nuclear Physics supported the enabling technologies

- Segmented Detector Fabrication
- Mechanically cooled systems
- Large diameter crystal growth

Small Business Innovation ×

rgy.gov/np/benefits-of-np/sbir-sttr/

Nuclear Physics (NP)

- NP Home
- About
- Research
- Facilities
- Science Highlights
- Benefits of NP
  - Applications of Nuclear Science
  - Small Business Innovation / Technology Transfer
- Funding Opportunities
- Nuclear Science Advisory Committee (NSAC)
- News & Resources

CONTACT INFORMATION

Nuclear Physics
U.S. Department of Energy
SC-26/Germantown Building
1000 Independence Ave., SW

Benefits of NP

Small Business Innovation / Technology Transfer

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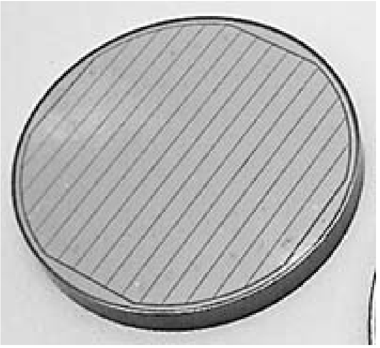
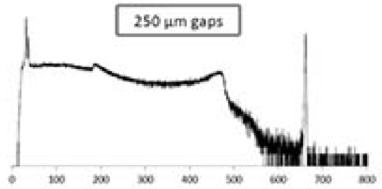




Segmented Rectifying and Blocking Contacts on large diameter Germanium Planar Detectors developed by PhD Co. (Phase II SBIR awards) and evaluated at UMass Lowell. This Contact fabrication technology transitioned into commercial detector fabrications and used in commercial gamma ray detectors such as Germanium Gamma Ray Imager (GeGI shown above) and Germinium Gamma Camera (GGC) (see PhD Co. presentation at 2013 Exchange Meeting)

NP SBIR/STTR Exchange Meeting

In November 2013, the Office of Nuclear Physics (NP) organized a two day information exchange meeting between the representatives of SBIR/STTR companies with active Phase II grants supported by NP, scientists and engineers from the NP community, and NP Federal Program Managers. The meeting included presentations from the SBIR/STTR companies on their research and presentations on the relevant technical needs of the NP community. The 2014 Phase II Exchange meeting will be held on August 6 and 7, 2014. Information on past meetings are available at the following links:

- 2013 Exchange Meeting
- 2012 Exchange Meeting
- 2011 Exchange Meeting

Basic Contact Physics – the need for barriers on HPGe detectors

HPGe

$|N_A - N_D| \sim 10^{10}\ /cm^3$
$\mu \sim 4\times10^4\ cm^2/Vs$ (77 K)

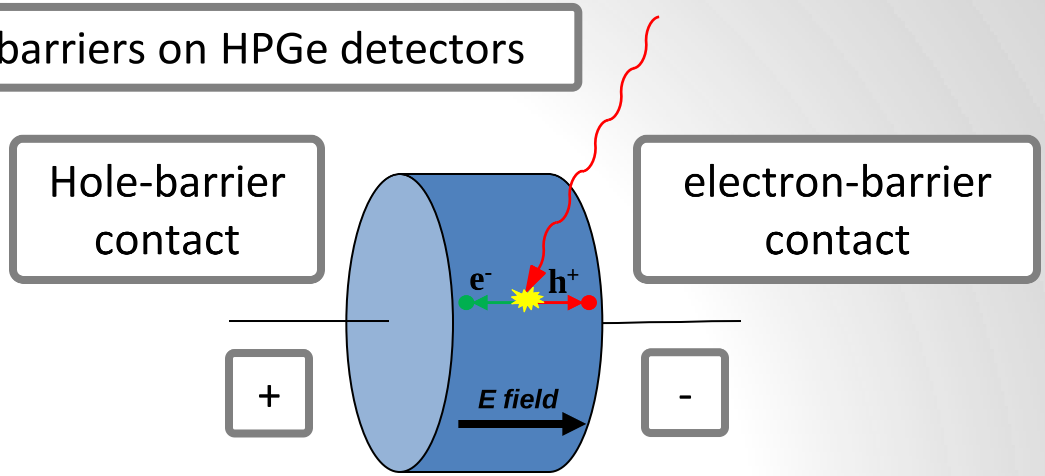
$\rho \sim 15\ k\Omega\ cm$

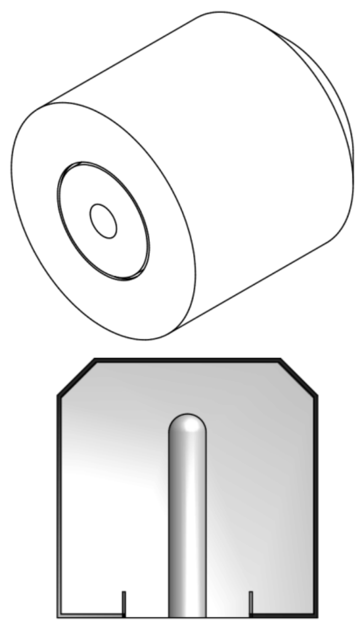
$1\ cm^3$, $1\ V \sim 67\ \mu A$!!!!

Resistivity is far too low

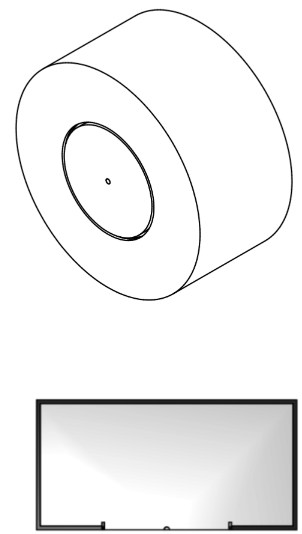
Contacts must form charge-injection barriers

Electric Field
Low leakage current (~10 pA)
Low noise connection

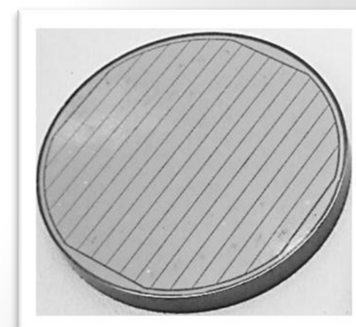




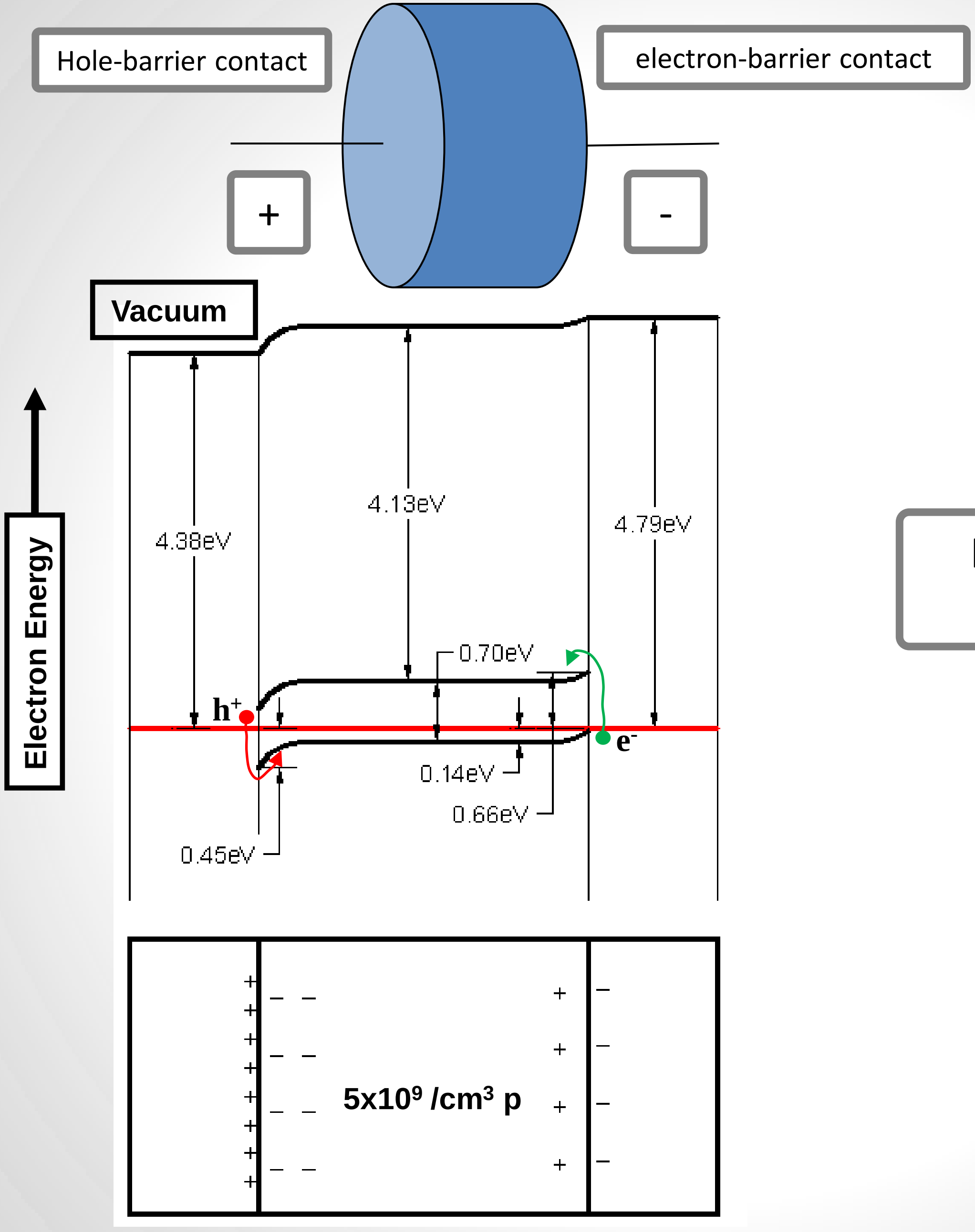
Coaxial Detector Li-diffused contact n+



P-type Point Contact Detector (PPC)
Li-diffused contact n+

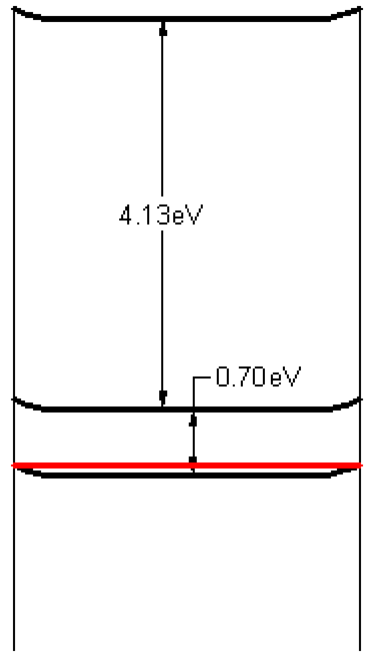


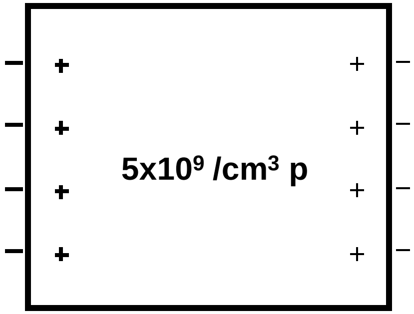
Orthogonal Strip Detector α-Ge



Ideal contact formation

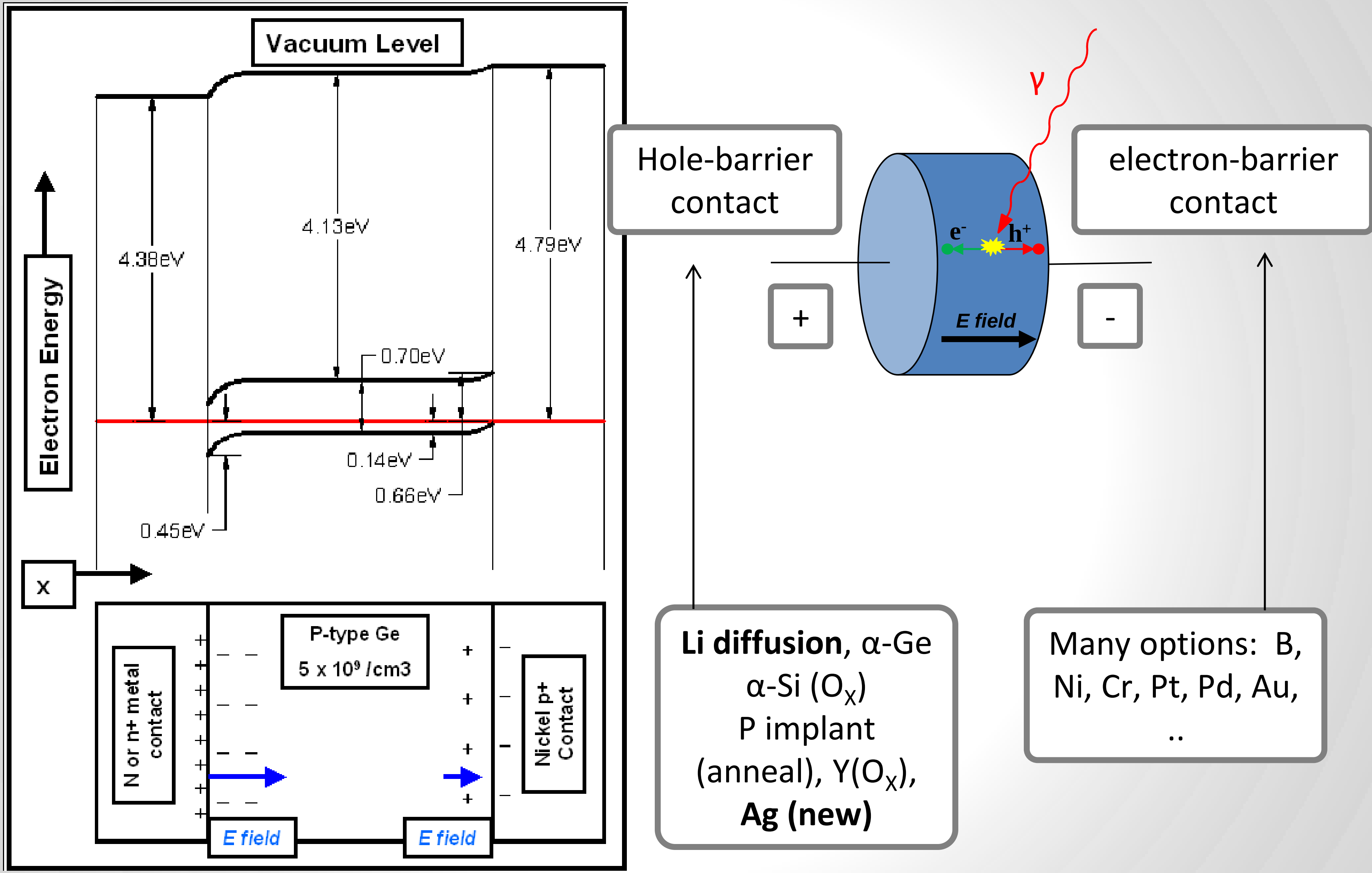
However…



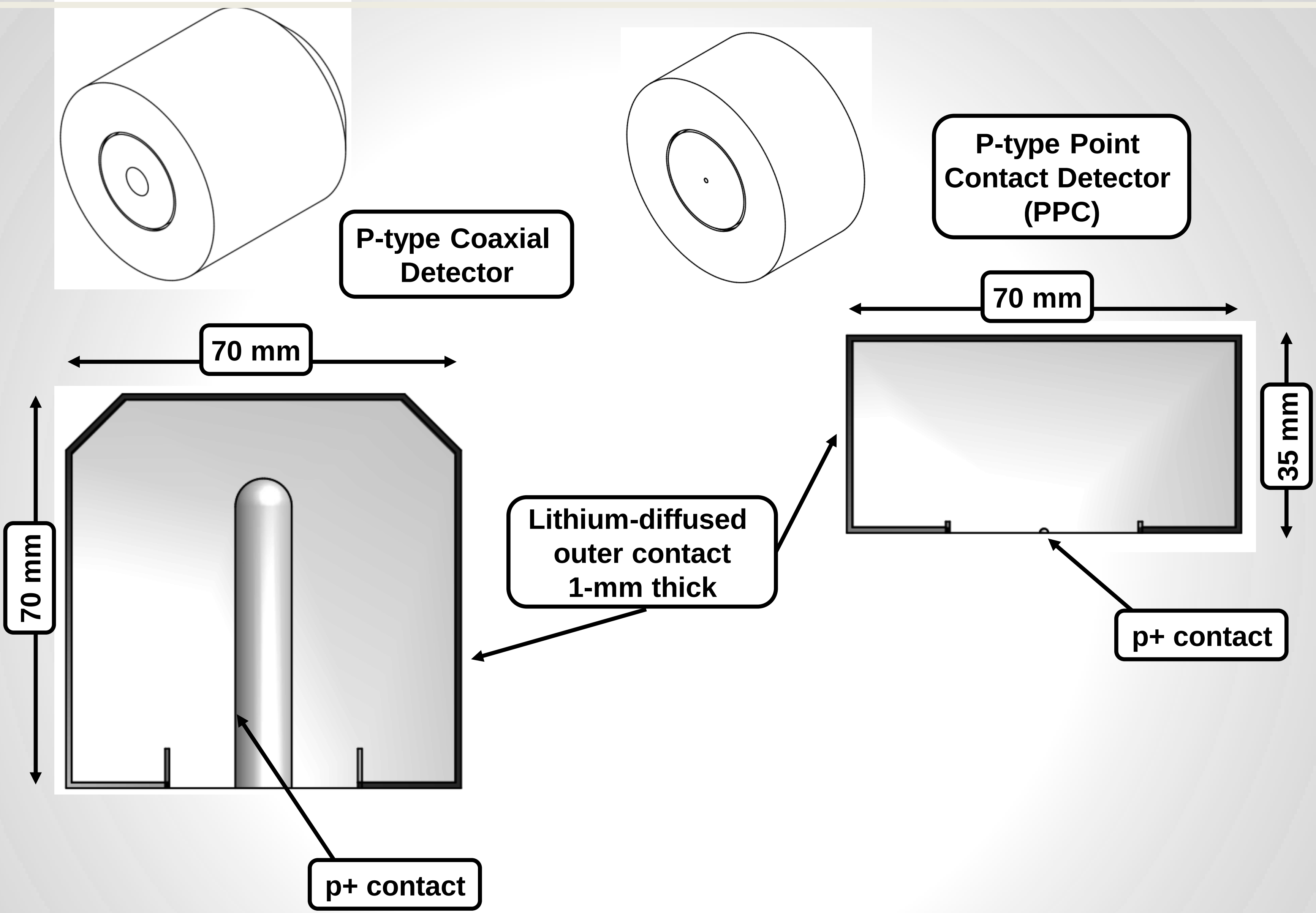


Damage is p-type (an acceptor state) in crystalline Ge

- Highly Stressed Crystals
  - Poly ZR Bars
  - Crystals grown and maintained at a high temperature too long
- Radiation damage from massive energetic particles (p, n, heavy ions)
- **Grinding, slicing, and etching!!!**
  - **Surfaces become p-type – this makes it very difficult to fabricate the hole-barrier (n+) positively biased contact**
  - Passivation is an attempt to neutralize this α-Ge

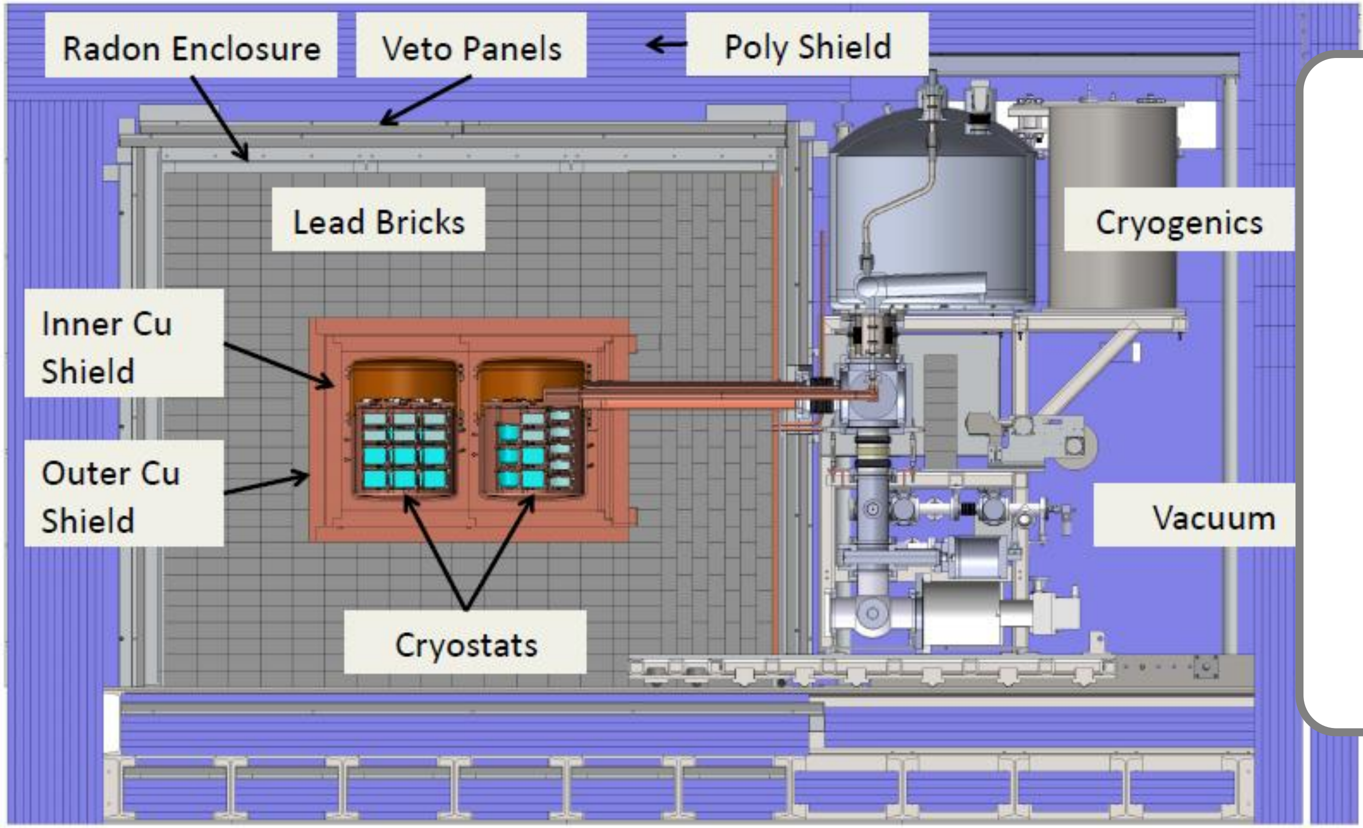


Vacuum Level
Electron Energy
4.38eV
4.13eV
4.79eV
0.70eV
0.14eV
0.66eV
0.45eV
x
N or n+ metal contact
P-type Ge
5 x 10⁹ /cm3
Nickel p+ Contact
E field
E field
Hole-barrier contact
electron-barrier contact
γ
e⁻
h⁺
E field
+
-
Li diffusion, α-Ge α-Si (O_X) P implant (anneal), Y(O_X), Ag (new)
Many options: B, Ni, Cr, Pt, Pd, Au, ..



7-8 % of the detector is Li dead layer

The MAJORANA DEMONSTRATOR



Majorana

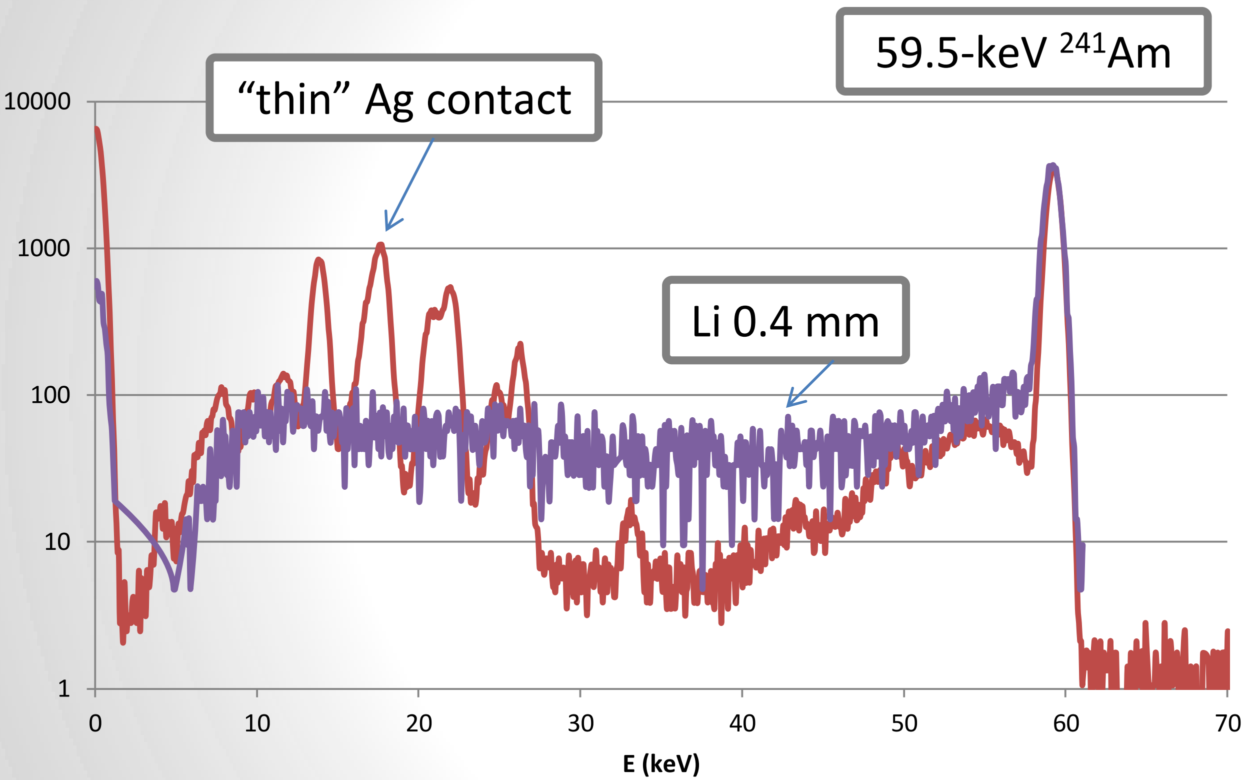
Goal: 1000kg ^{76}Ge

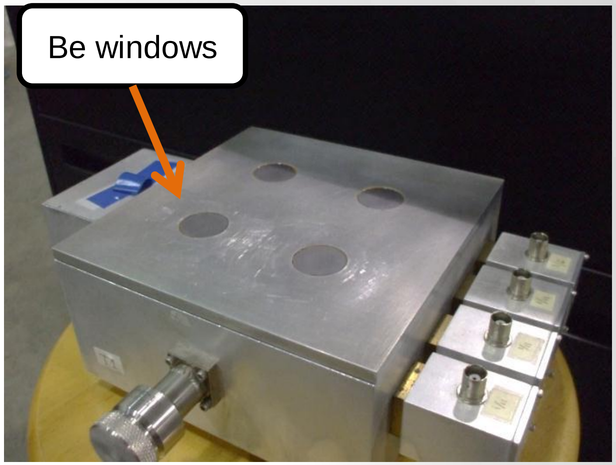
^{76}Ge \$100-\$200/g

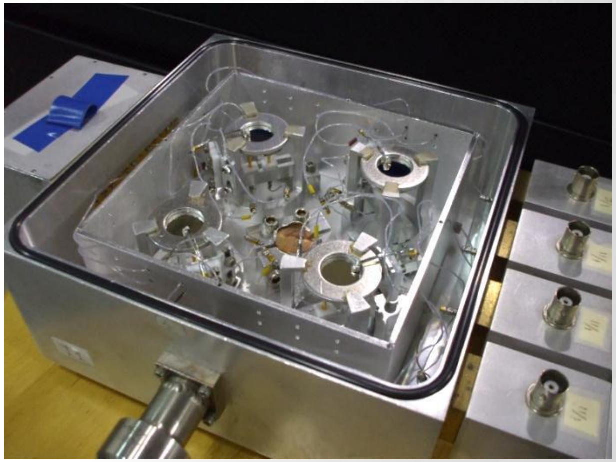
7% loss is \$7M-14M due to Li-diffused contact

1. Thick lithium-diffused contacts result in a loss of valuable material.

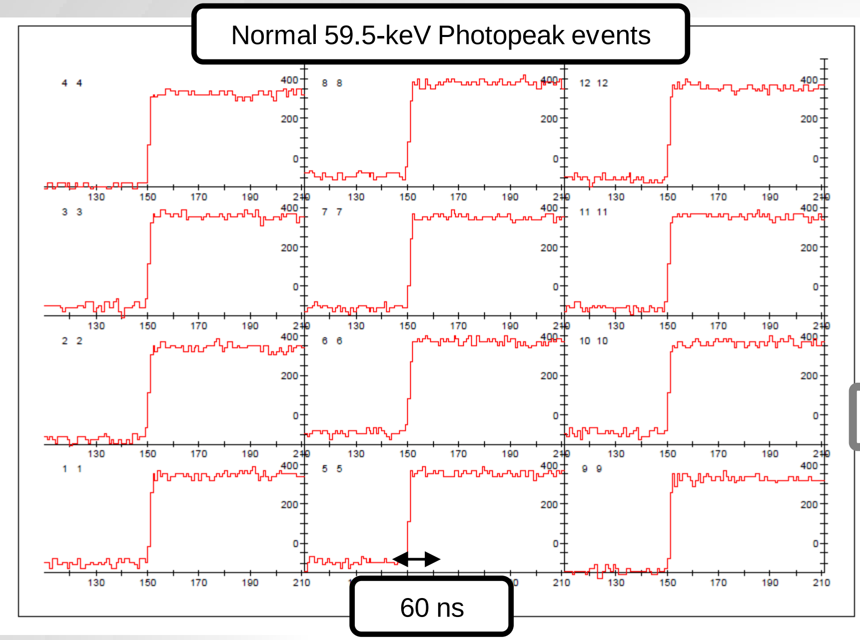
2. Thick lithium-diffused dead layer causes spectral artifacts

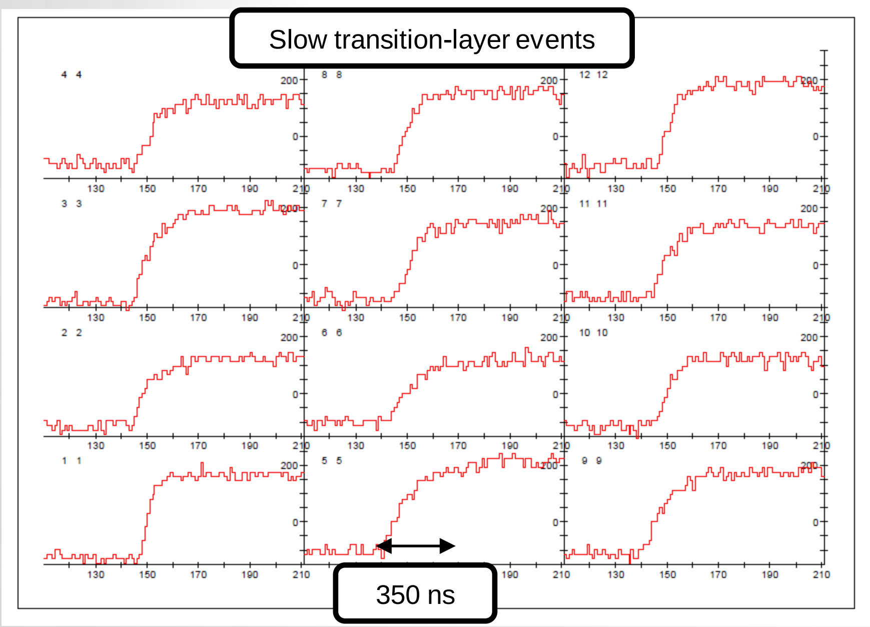


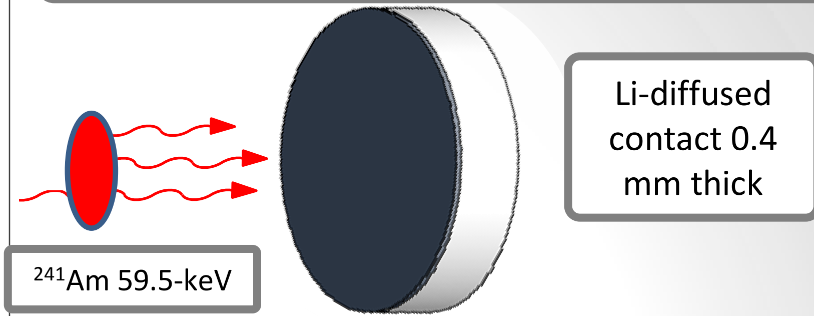


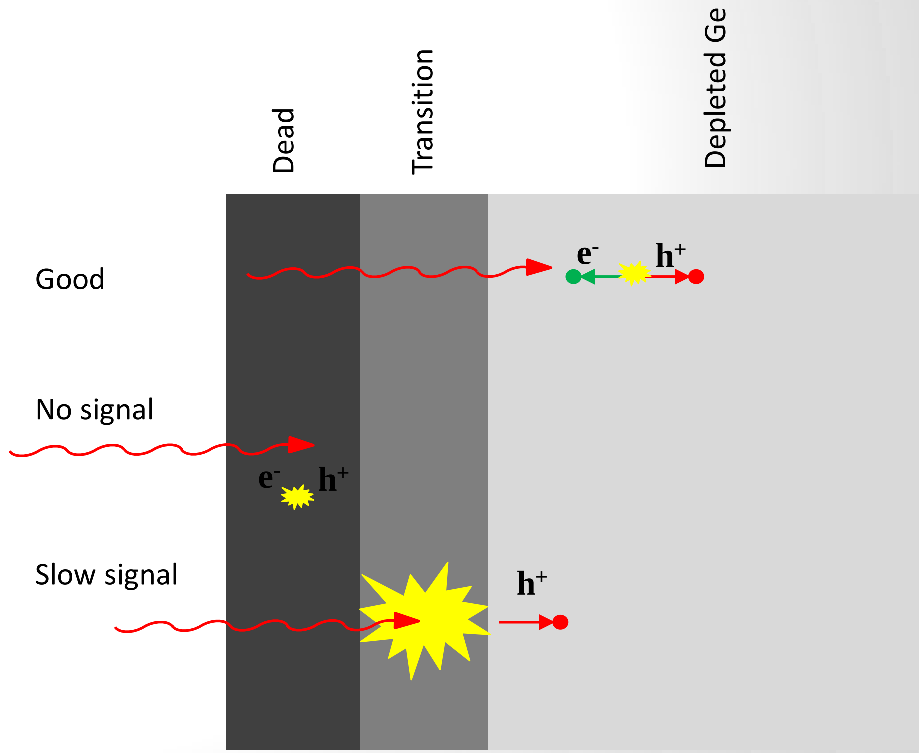


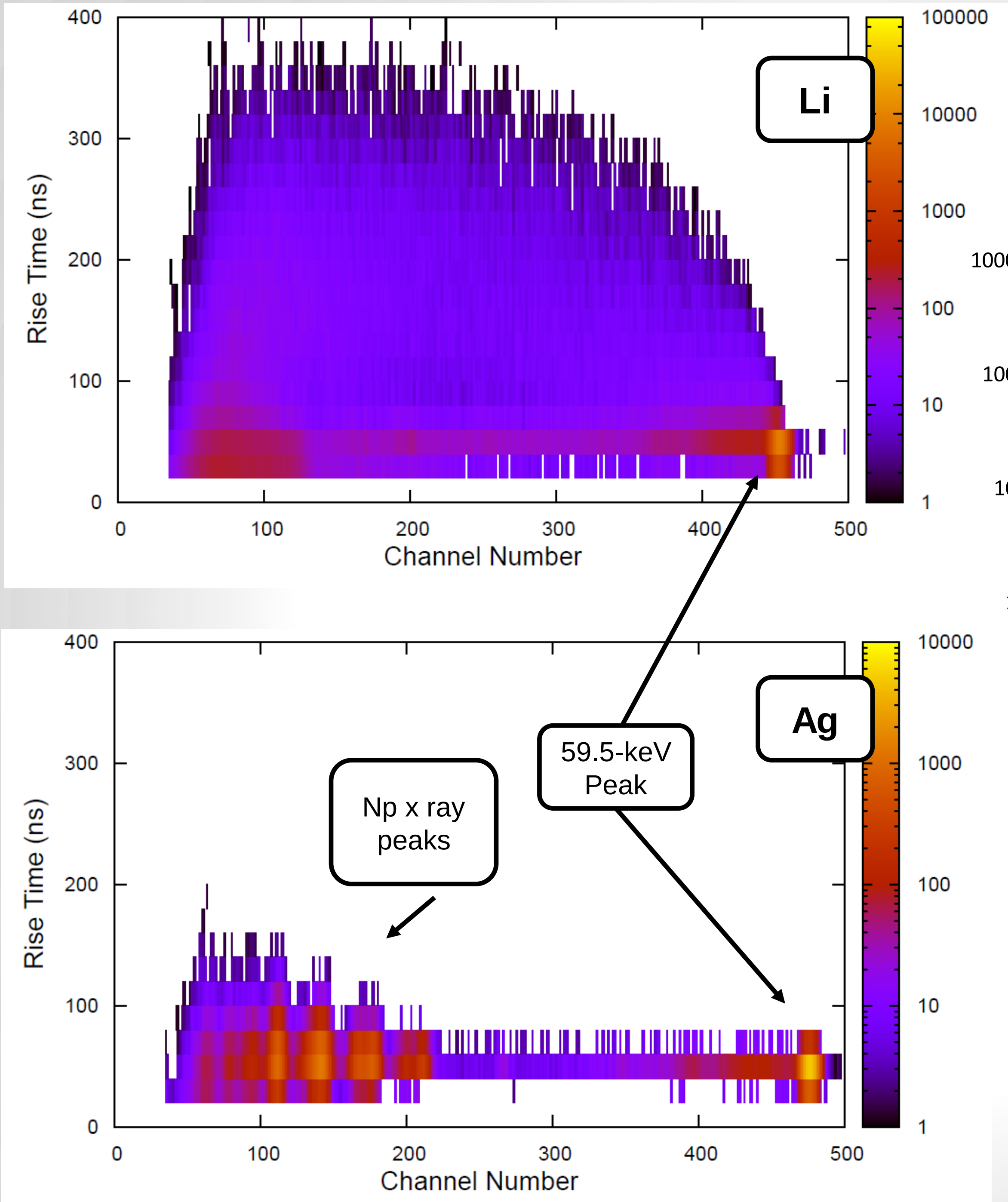
2a. Thick lithium-diffused show slow pulses from a "Transition Layer"
David Radford

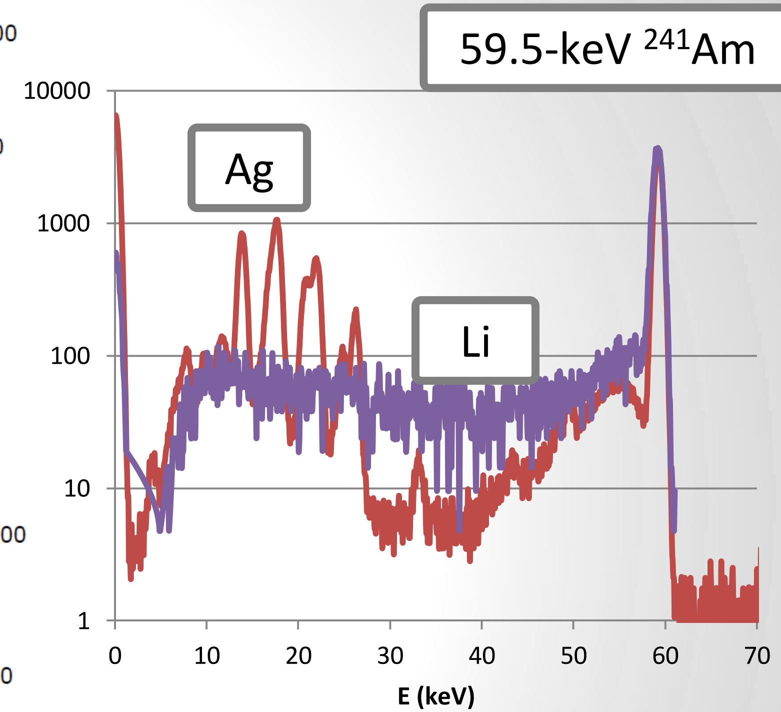












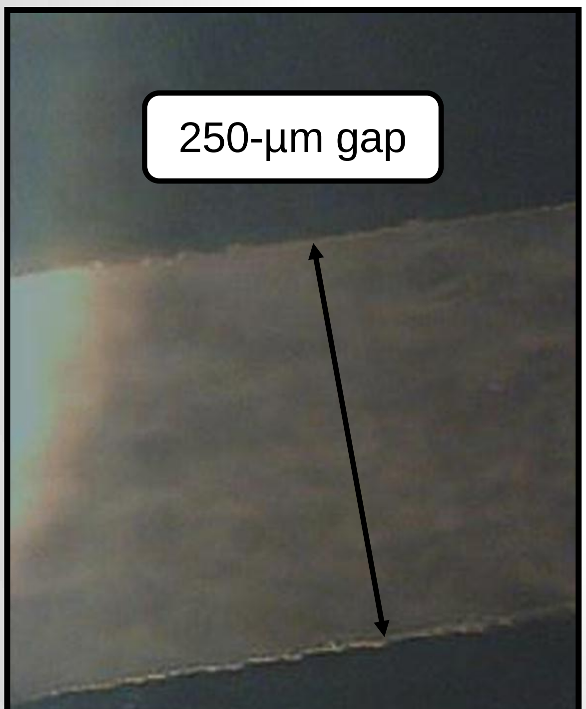
New Ag contact is “thin”

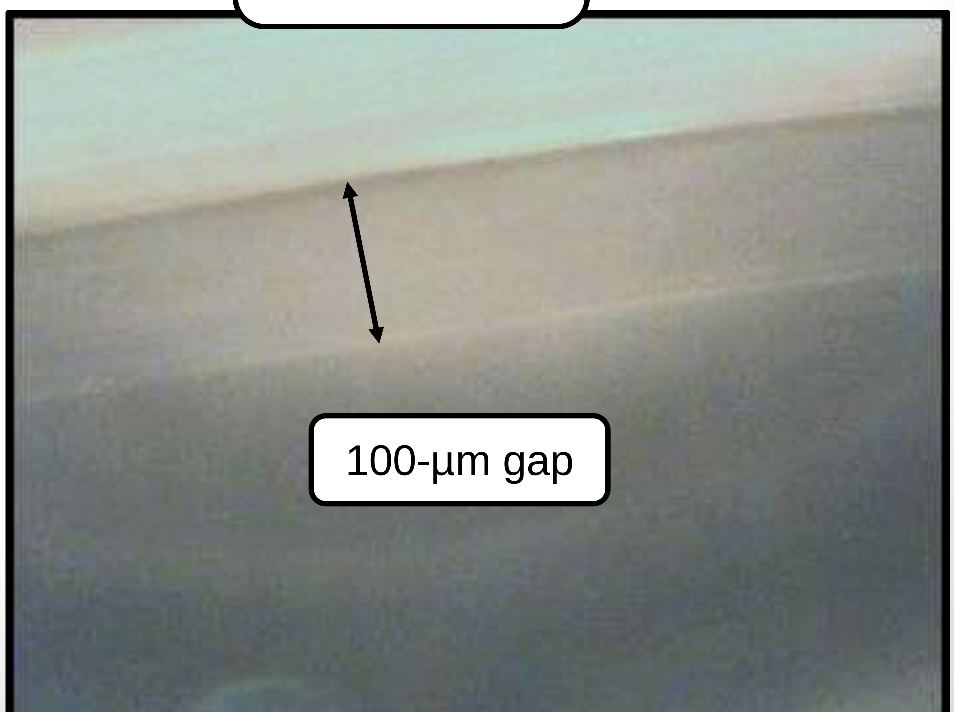
No slow pulses

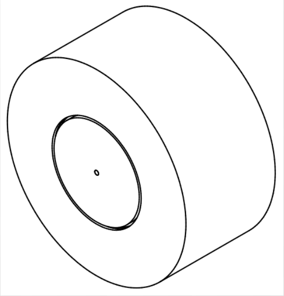
No wasted material

Ag contact

- Forms hole-barrier!
- Good resolution
- Chemical tolerant
- Good definition
- Sputter wraps
- Passivation viable

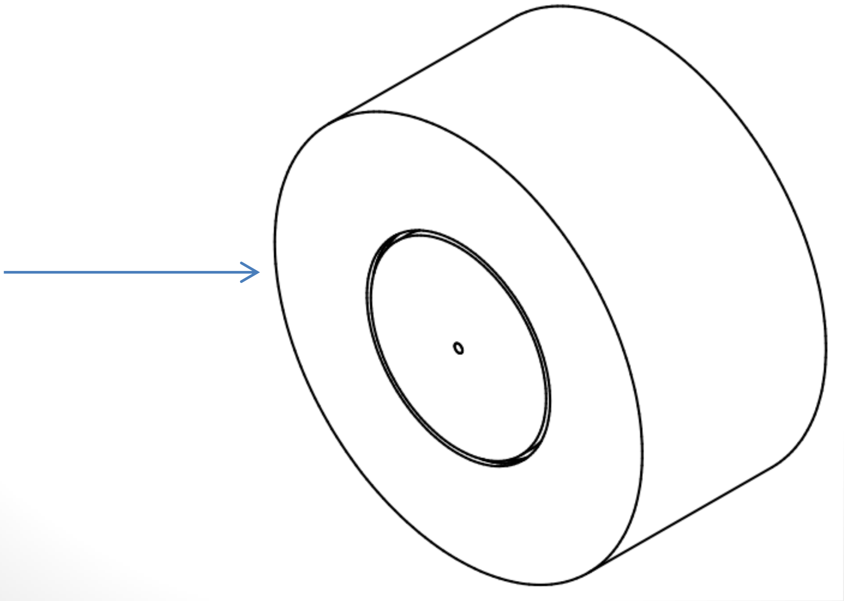






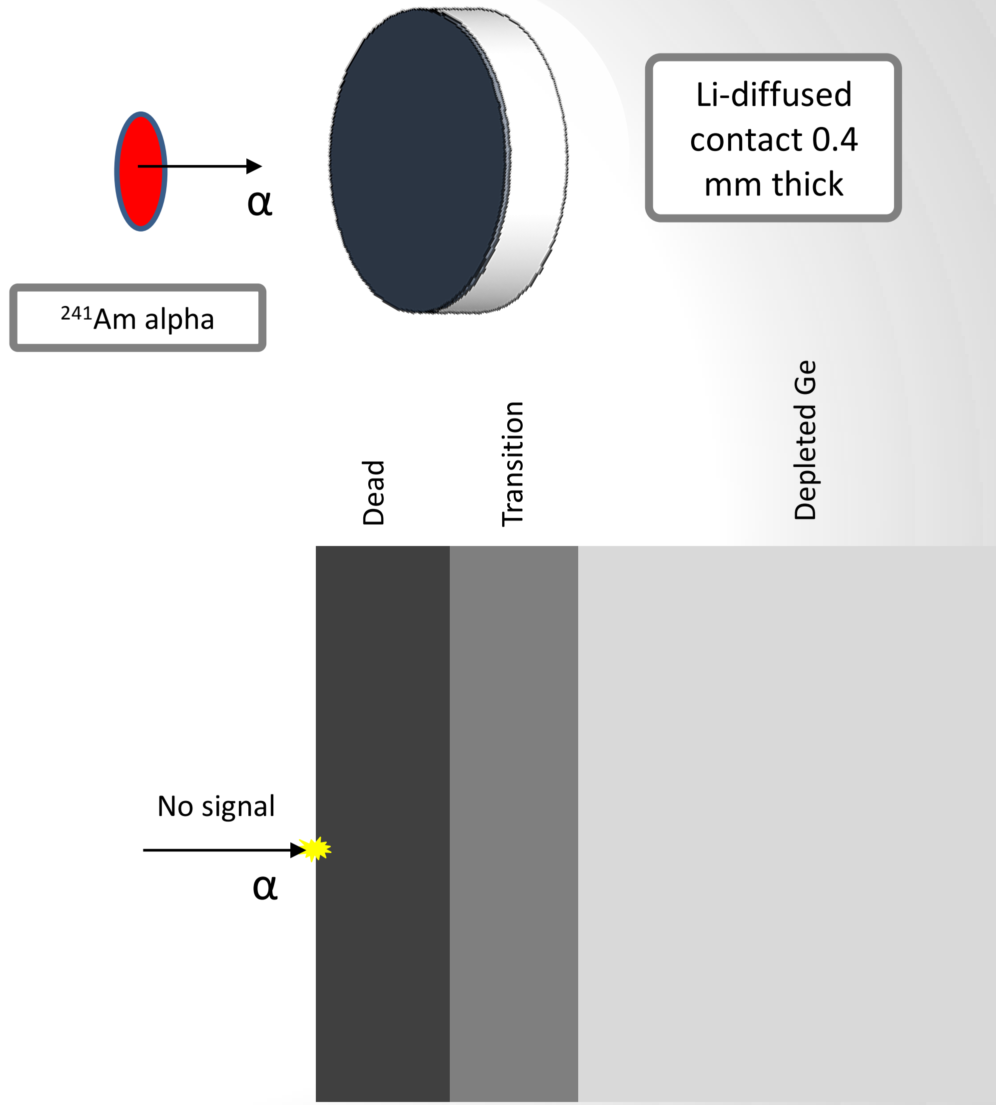
Ag contact

- Adapt from test detectors to ppcs
- **Look at Ag detectors with an alpha-particle source**
  - **Measure the true thickness.**
  - **Evaluate the implications of alpha-particle background**

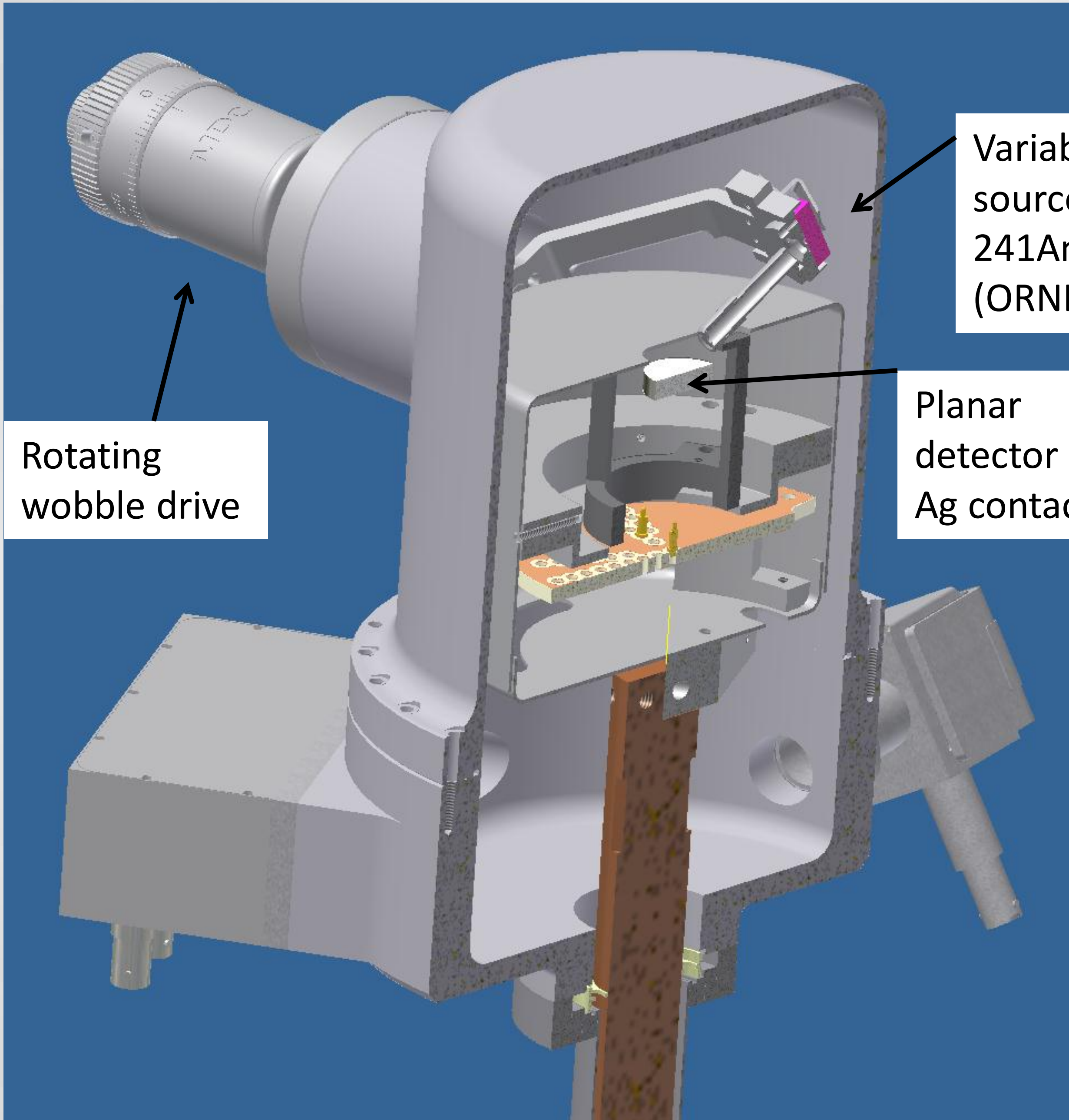


Thick Li-diffused contact has the single redeeming quality that it stops alphas (5 MeV) in 20 µm.

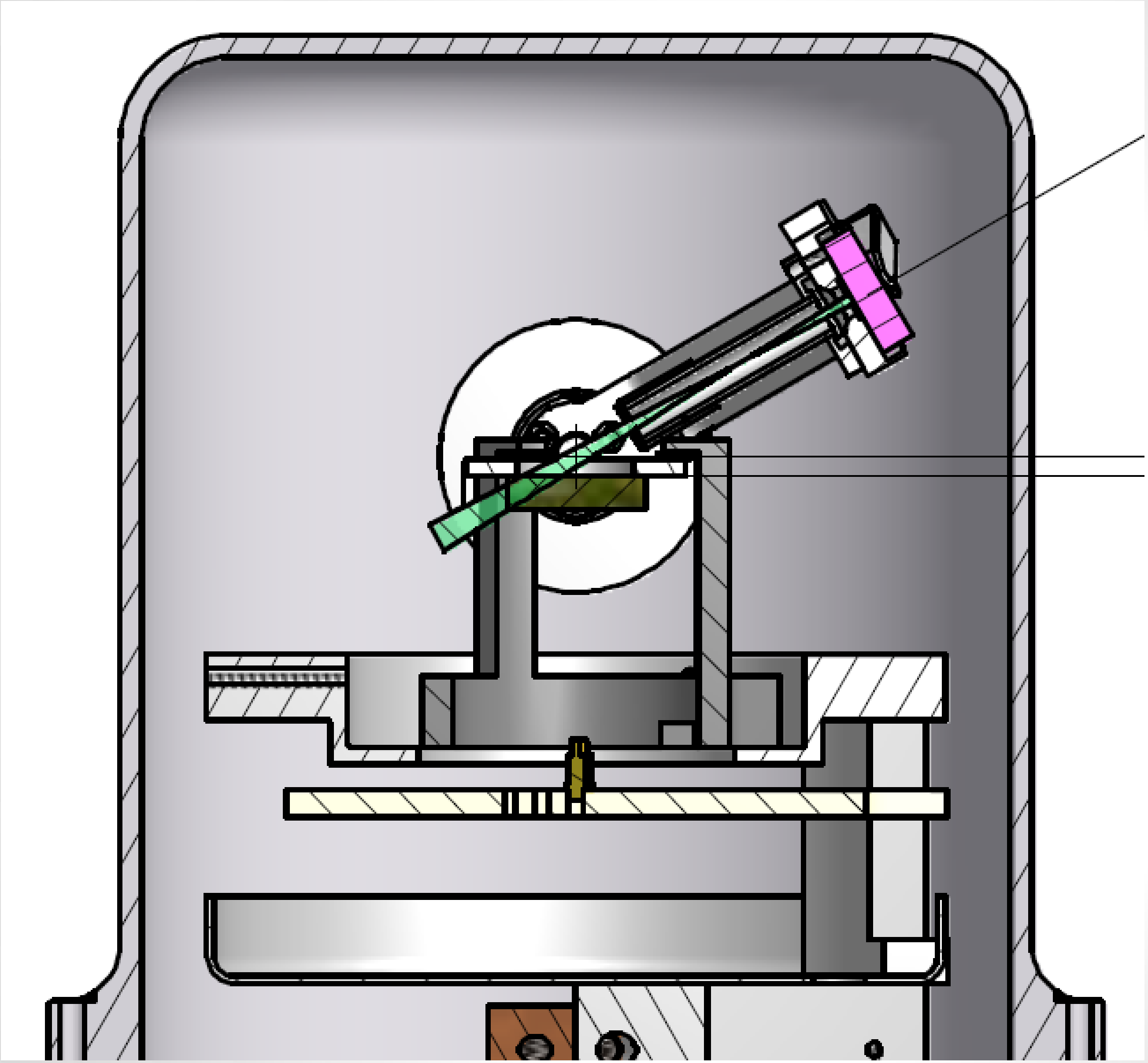
This has important background implications for low-level counting.



MJ1 Cryostat

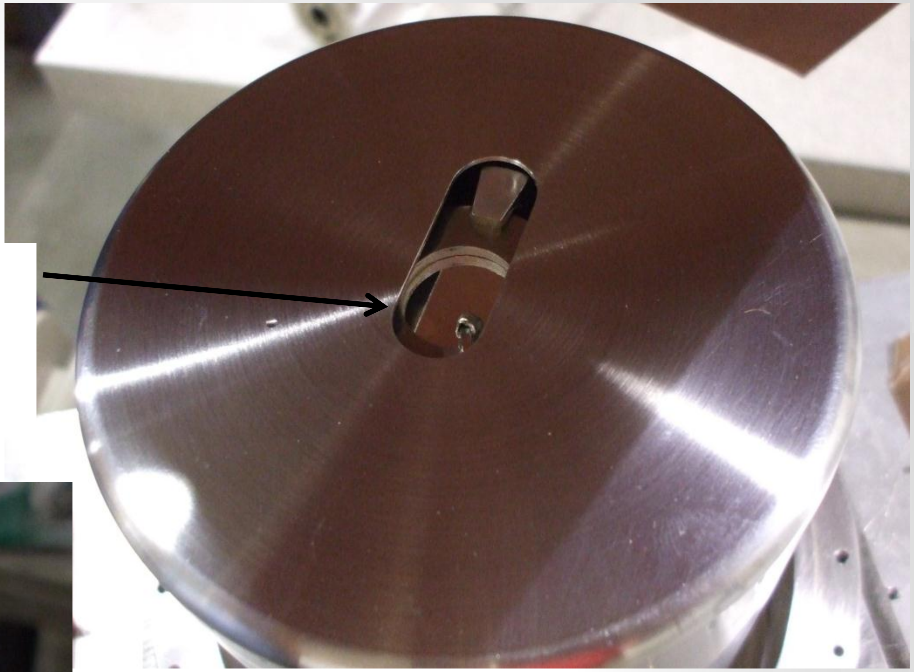


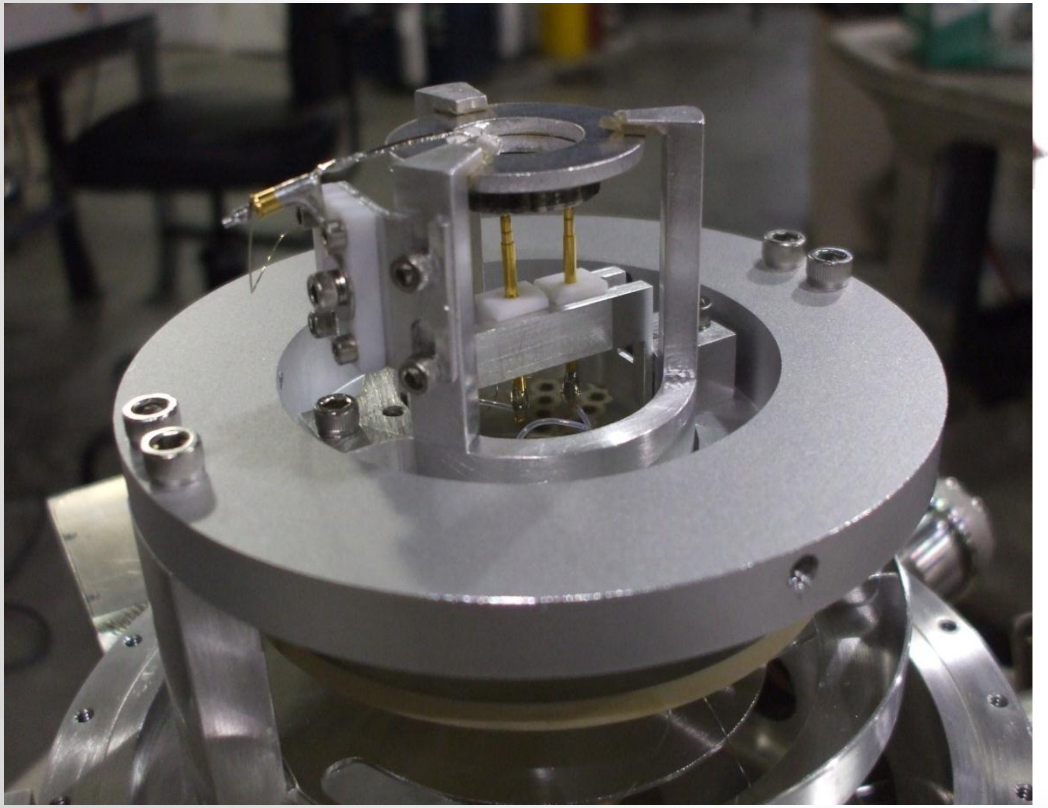
Focus on evaluating the Ag contact on small planar detectors.

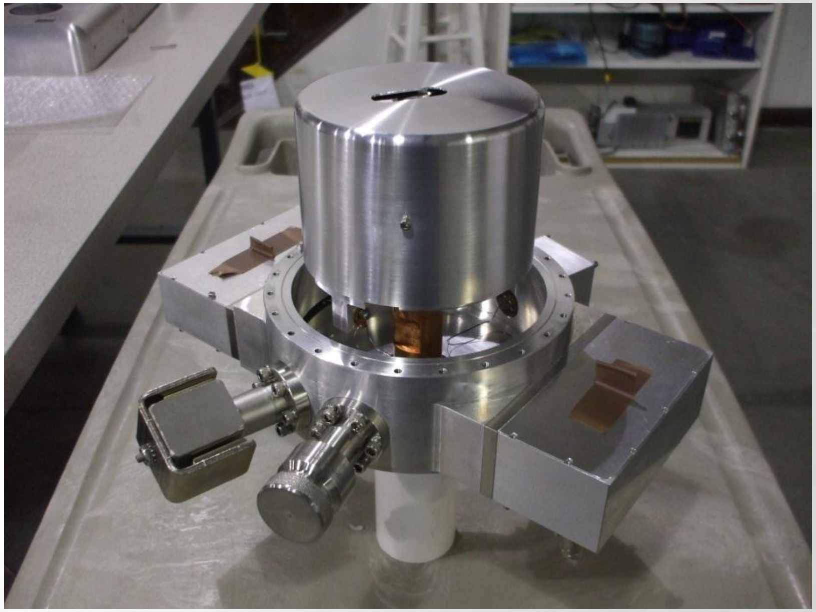


P-type HPGe 5 mm thick
V_{depl} = + 130 V (9.2×10^9 /cm^3)
V_{op} = + 600 V

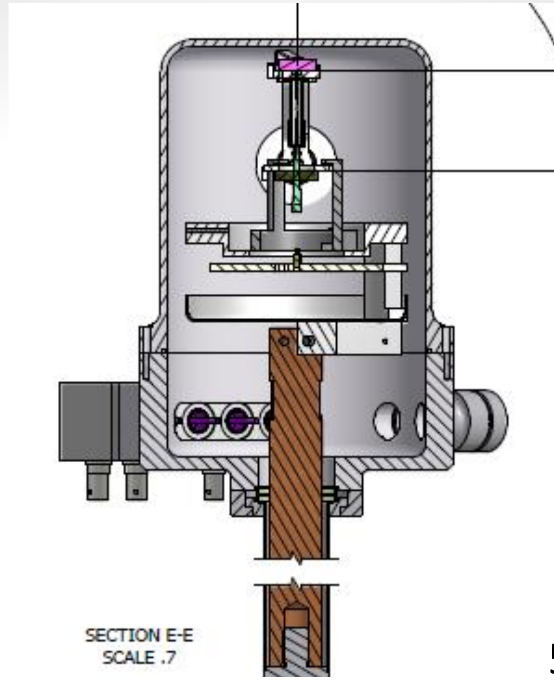
Ag contact on planar HPGe detector







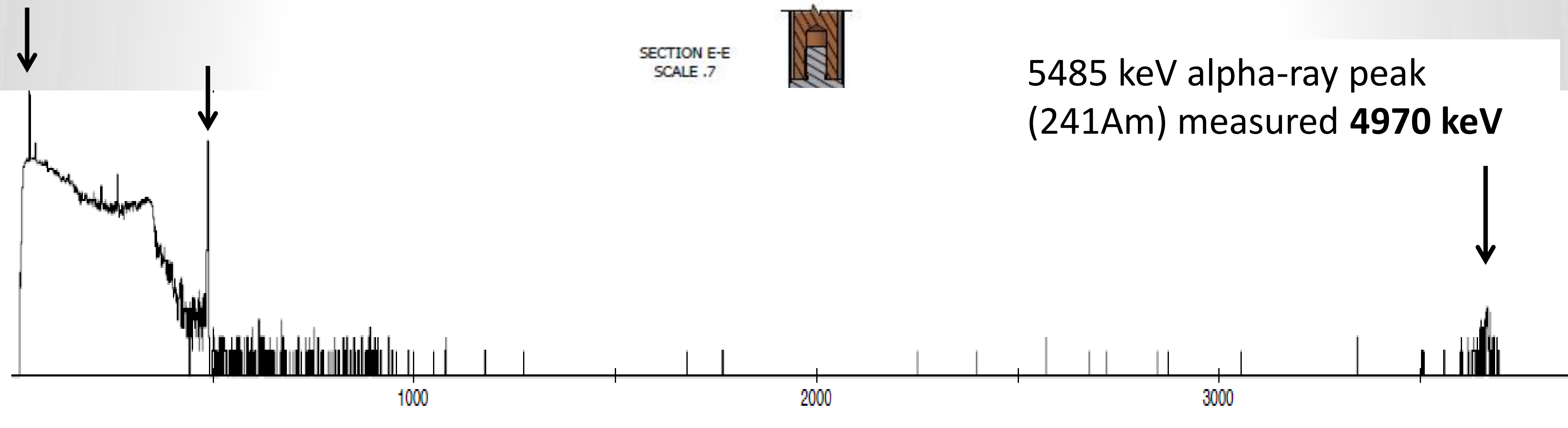
Absolute E cal



0° incidence

59.5 keV and 662 keV gamma rays [Calibrate]

5485 keV alpha-ray peak (241Am) measured **4970 keV**



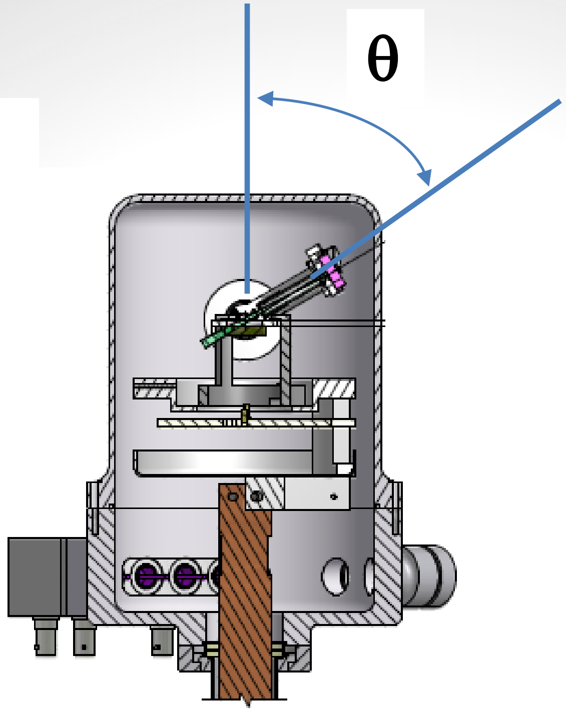
dE/dx ~ 20 eV/Å for a 5-MeV alpha in Ge

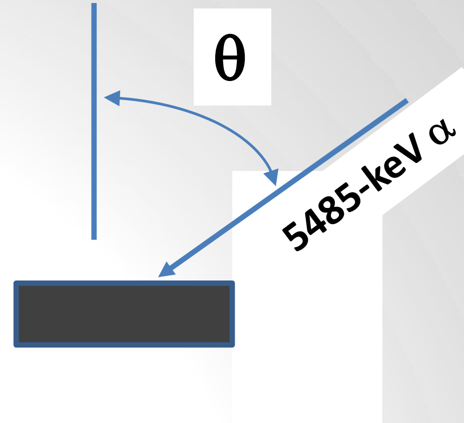
5485 keV – 4970 keV = 515 keV

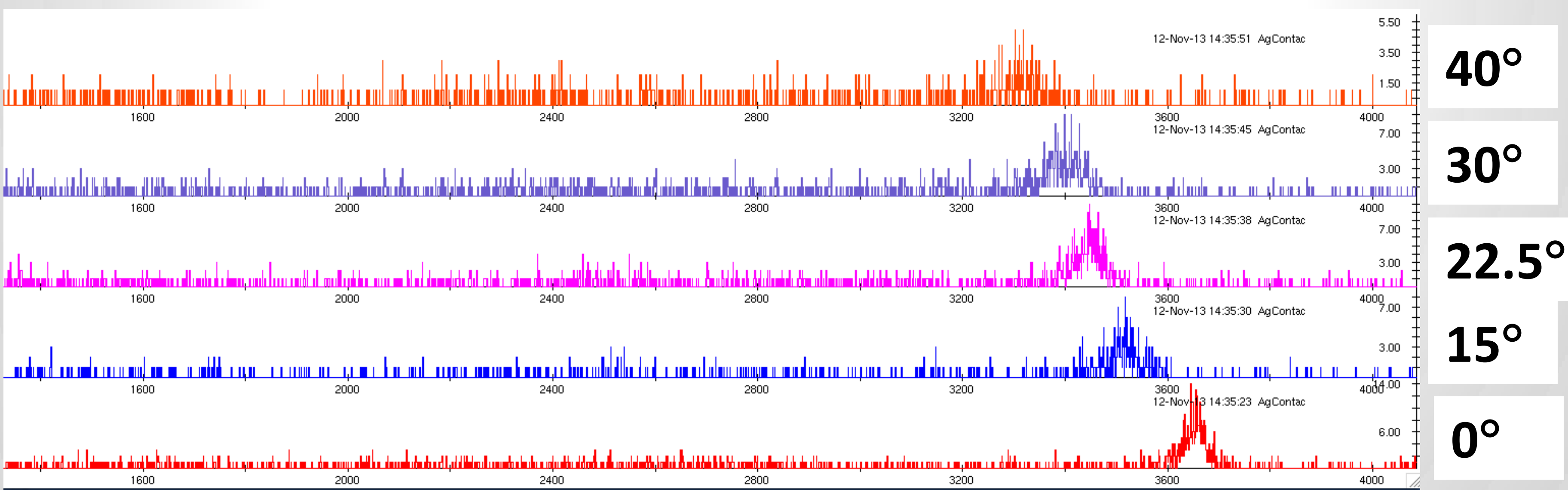
515 keV / 20 eV/Å = **25750 Å = 2.6 μm**

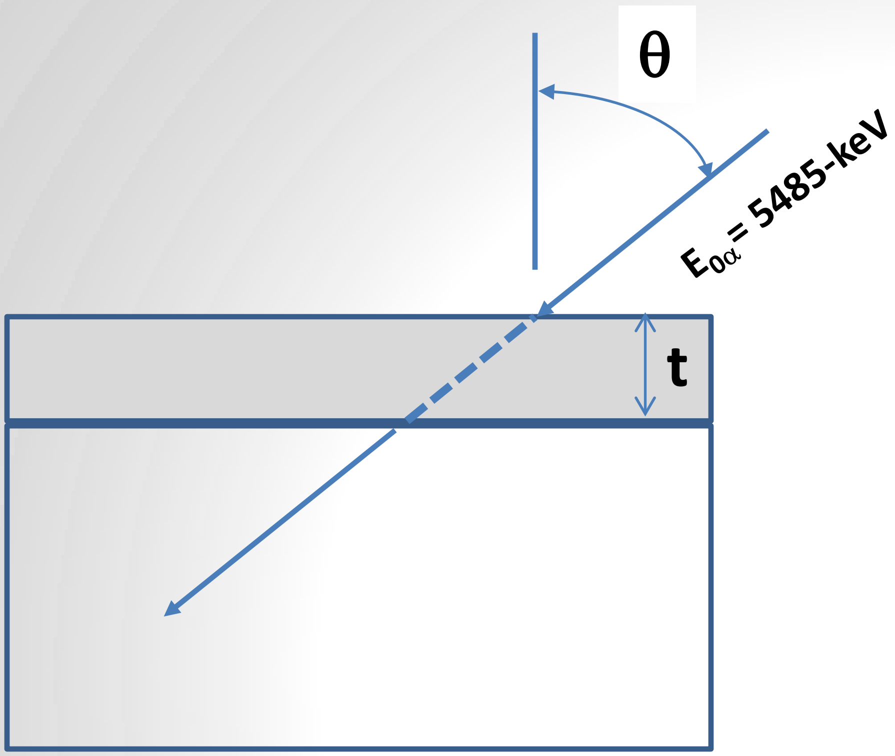
→ The Ag contact may be quite thick. ??? Calibration?

Peak shift vs. angle of incidence

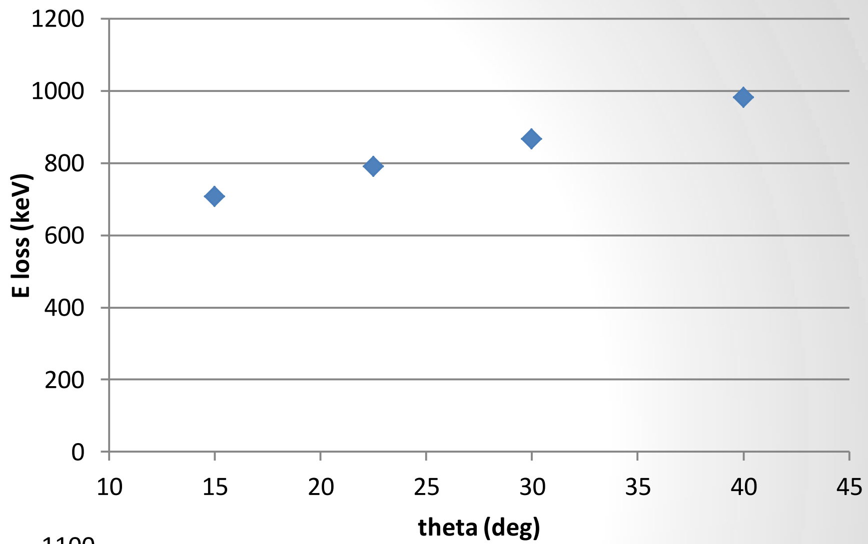


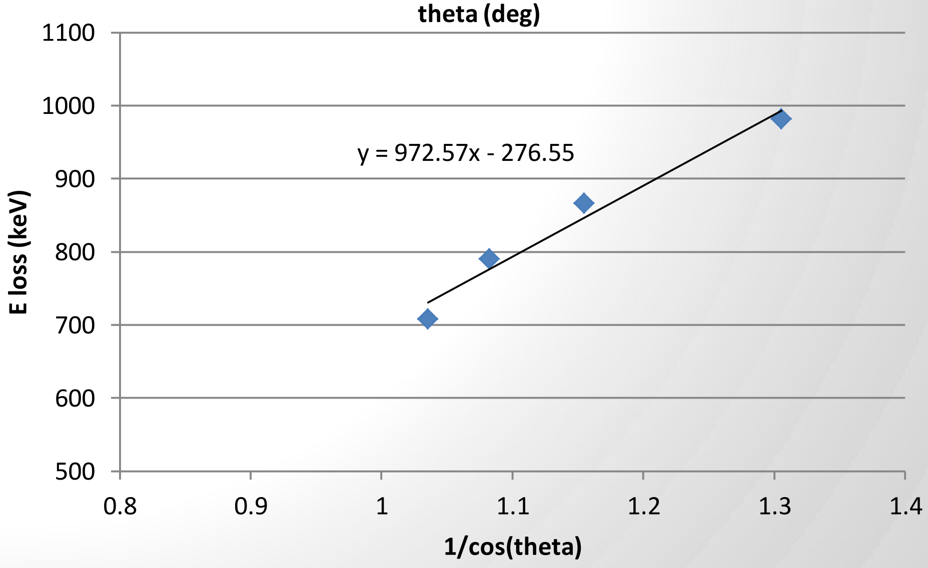






E_{loss} = (dE/dx) **t**/cos(θ)

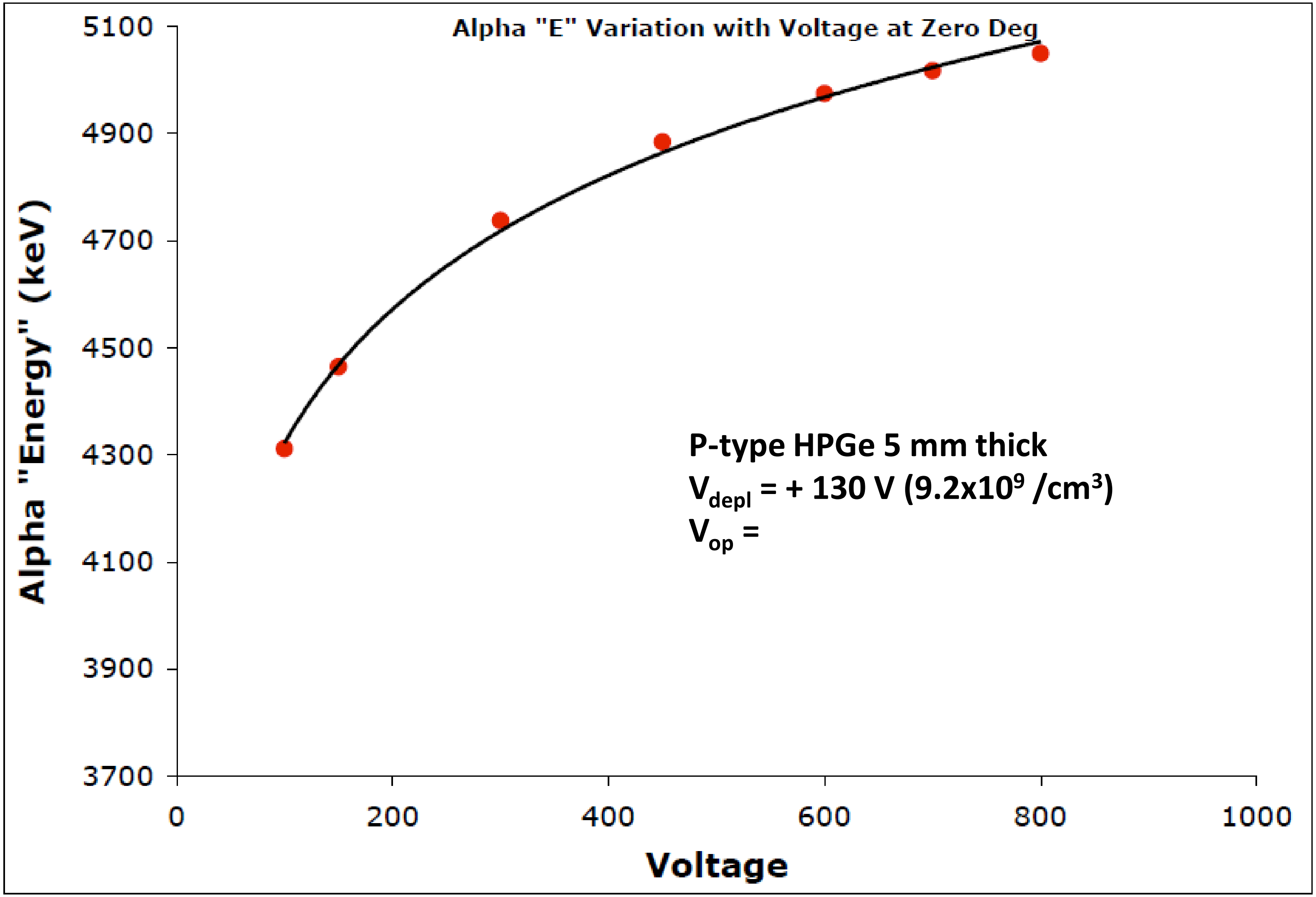




t = 973 keV/0.020 keV/A
= 48,650 A = **4.9 μm**

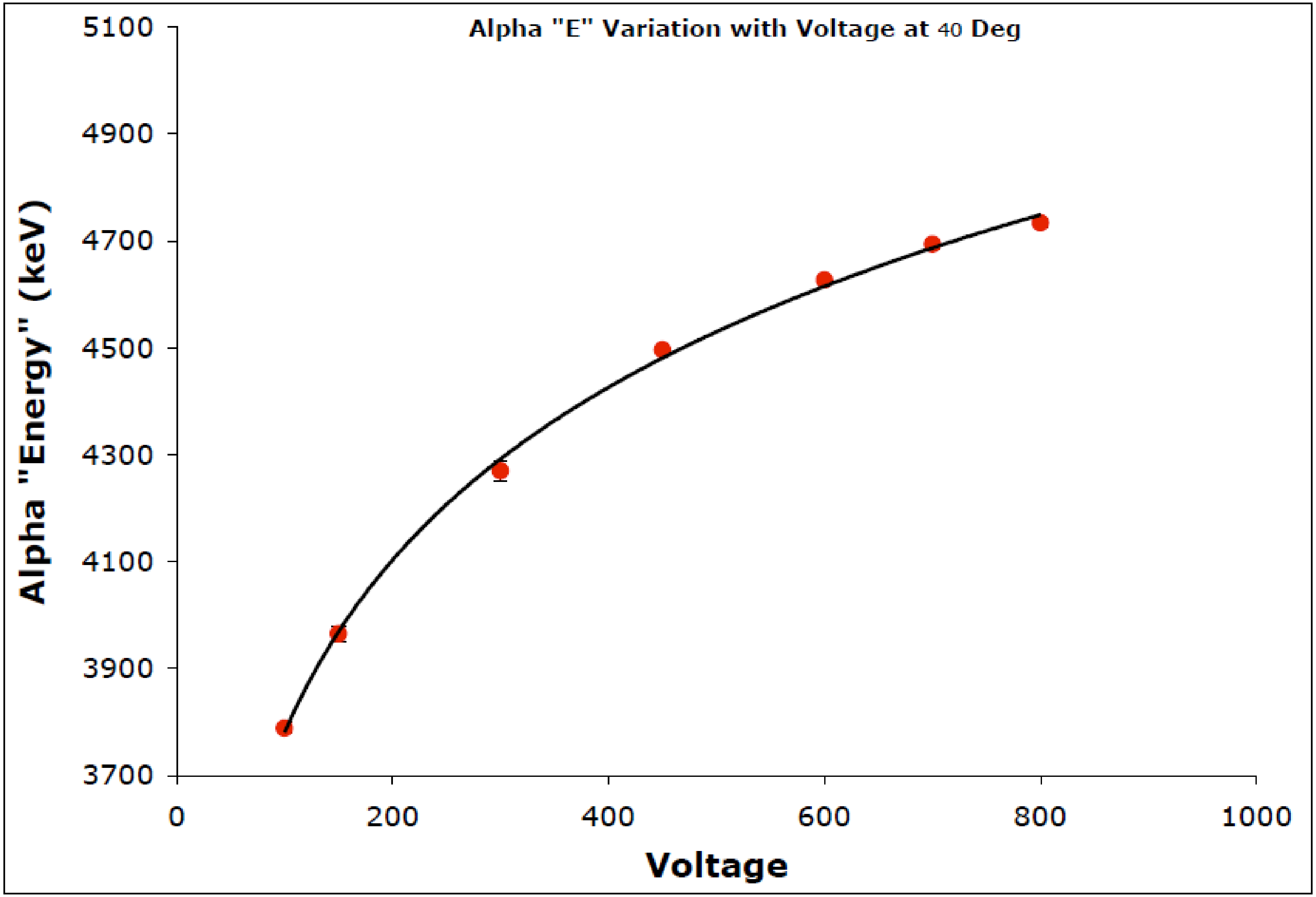
→ **The dead layer is thick.!!**

0°

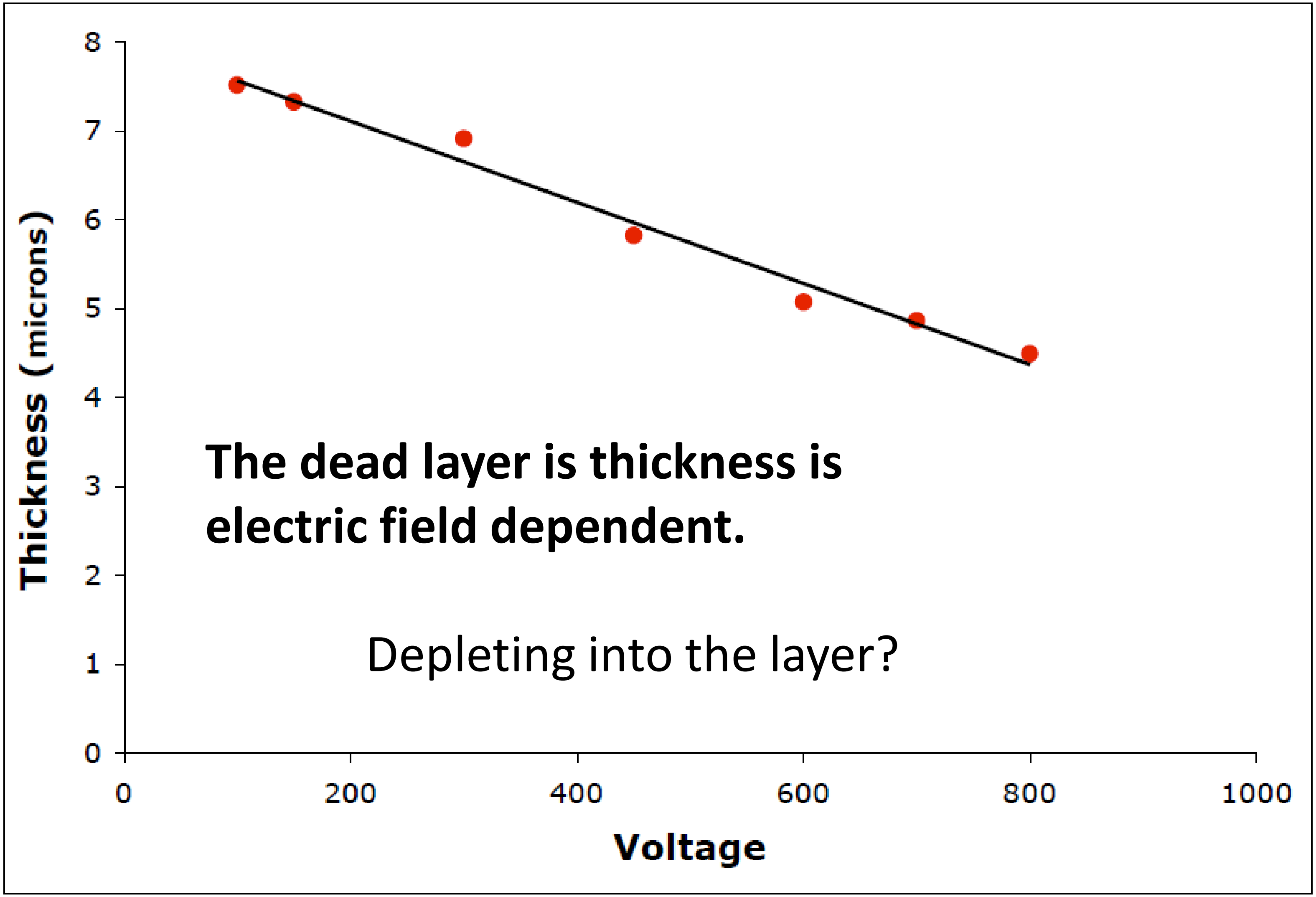


Alpha "E" Variation with Voltage at Zero Deg
Alpha "Energy" (keV)
5100
4900
4700
4500
4300
4100
3900
3700
0
200
400
600
800
1000
Voltage
P-type HPGe 5 mm thick
V_{depl} = + 130 V (9.2x10^9 /cm^3)
V_{op} =

40°

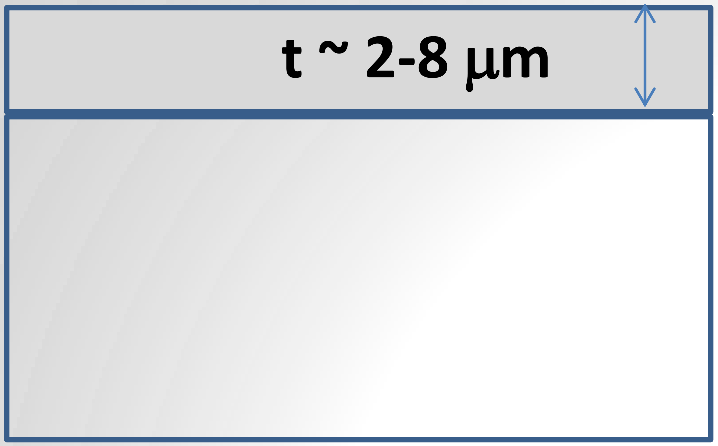


Alpha "E" Variation with Voltage at 40 Deg
Alpha "Energy" (keV)
5100
4900
4700
4500
4300
4100
3900
3700
0
200
400
600
800
1000
Voltage



The dead layer is thickness is electric field dependent.

Depleting into the layer?



As measured by Alpha particles:

1. The dead layer is several microns thick.
2. The deal layer thickness is electric-field dependent.
3. Sputter deposited **Ag** and **αGe** contacts

Remarks

Surprising – 0.2 μm of material deposition

The dead layer is almost certainly not deposited material – it cannot change with electric field

Similar measurements (SANTA) have shown B implants to be 0.4 μm thick (20-100 keV implant)

Lithium is 1 mm thick .
"Thin" Schottky contacts are 500-2000 A thick
Micron thickness is difficult to explain!!

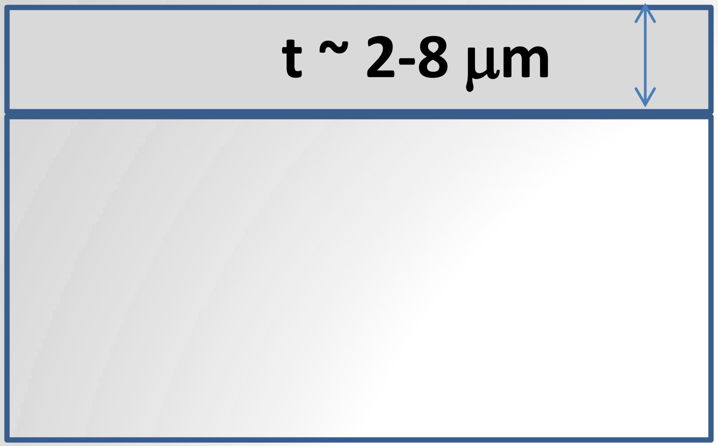
Conclusion

The dead layer is a semiconductor-physics effect inside the crystalline germanium.

Proposed mechanism: A highly damaged layer of germanium extending several microns into the crystal is formed during the sputter-deposition process (10-100 eV).

Thermally evaporated contacts (0.2 eV) are being evaluated now.

Already useful…

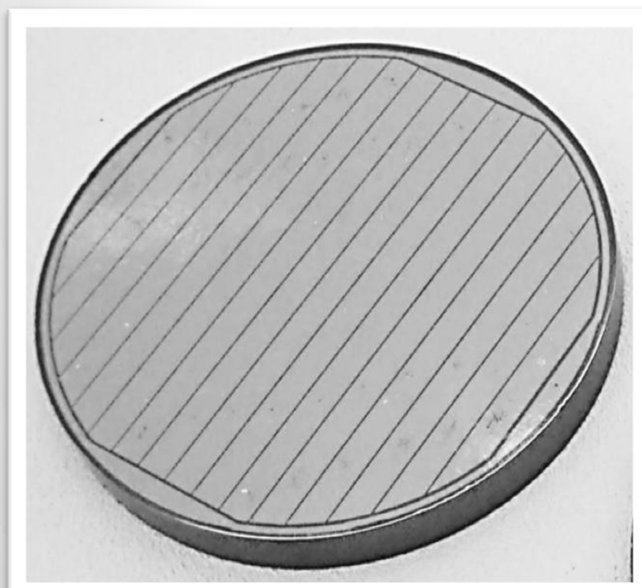


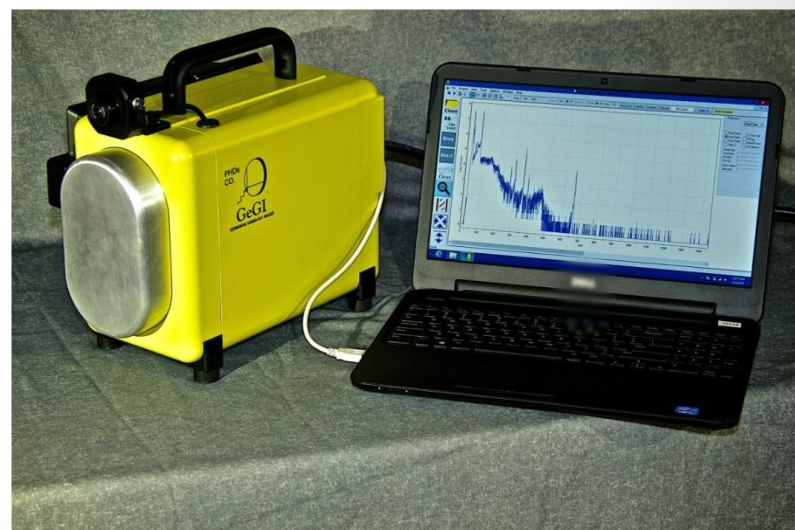
Damage is important and it is quite thick.

Shorter acid etch times to preserve previous damage

Better yield !!
Saves HPGe – more chances per wafer

Commercial detector process has been modified
→ Fabrication is being used for GeGI detectors now.





GeGI®

Gamma-Ray Imaging Detector

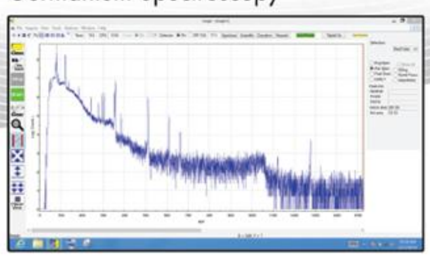
Where it is...
What it is...
Without getting close.

Wide Angle Camera Captures the Field of View

Applications

Nuclear Power
Isotope Production
Radiopharmaceuticals
Nuclear Materials Management
Safeguards
Decommissioning
Demolition
Decontamination

Germanium Spectroscopy



Reduce Rad Worker Exposure

PHDS© Gamma Ray Imaging Detectors

Specifications

Dimensions:	12 in x 9 in x 6 in
Weight:	28 lbs (+ 1.8 lbs LiPo battery or + 3.1 lbs NiMH battery)
Battery life:	6-8 hours (external LiPo 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
For a point source 10-μCi ^{137}Cs at 1 meter (3.3 μR/hr):	
Detection and ID time (662 keV) (8σ):	3.7 sec ± 1.0 sec
Location (Compton image) time:	30 sec ± 13 sec
Spectroscopy 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:	User specified peak energies (unlimited)
Detector (Ge crystal) dimensions:	90-mm diameter, 10-mm thick
Active Detector Volume:	55 cm³
Active Detector Area:	55 cm²
Cool-down time:	3.5 hours
Start-up time (cold):	2 minutes
Included:	Tablet, Laptop, Pelican case, Power supply w/charger, all cables, lifetime software upgrades

Optional Rolling Pinhole Imaging Platform
1-in thick Pb, 60-degree FOV

Features

Germanium gamma-ray spectroscopy
Full 360° Gamma-ray Imaging
Locates user-specified gamma rays including ^{235}U (186 keV) and ^{239}Pu (375 keV 414 keV)
Pinhole-aperture imaging capable
User-friendly tablet or laptop operation
Full session save and reload capability
Named-pipe data acquisition and system control
Full data-stream access
Wireless capable
Twist-lock mil-spec power connector
Long-lived mechanical cooler (5 years +)
Reach Back File: ANSI 42.42 format

Optional LiPo Battery Pack

Windows XP, 7, 8 compatible

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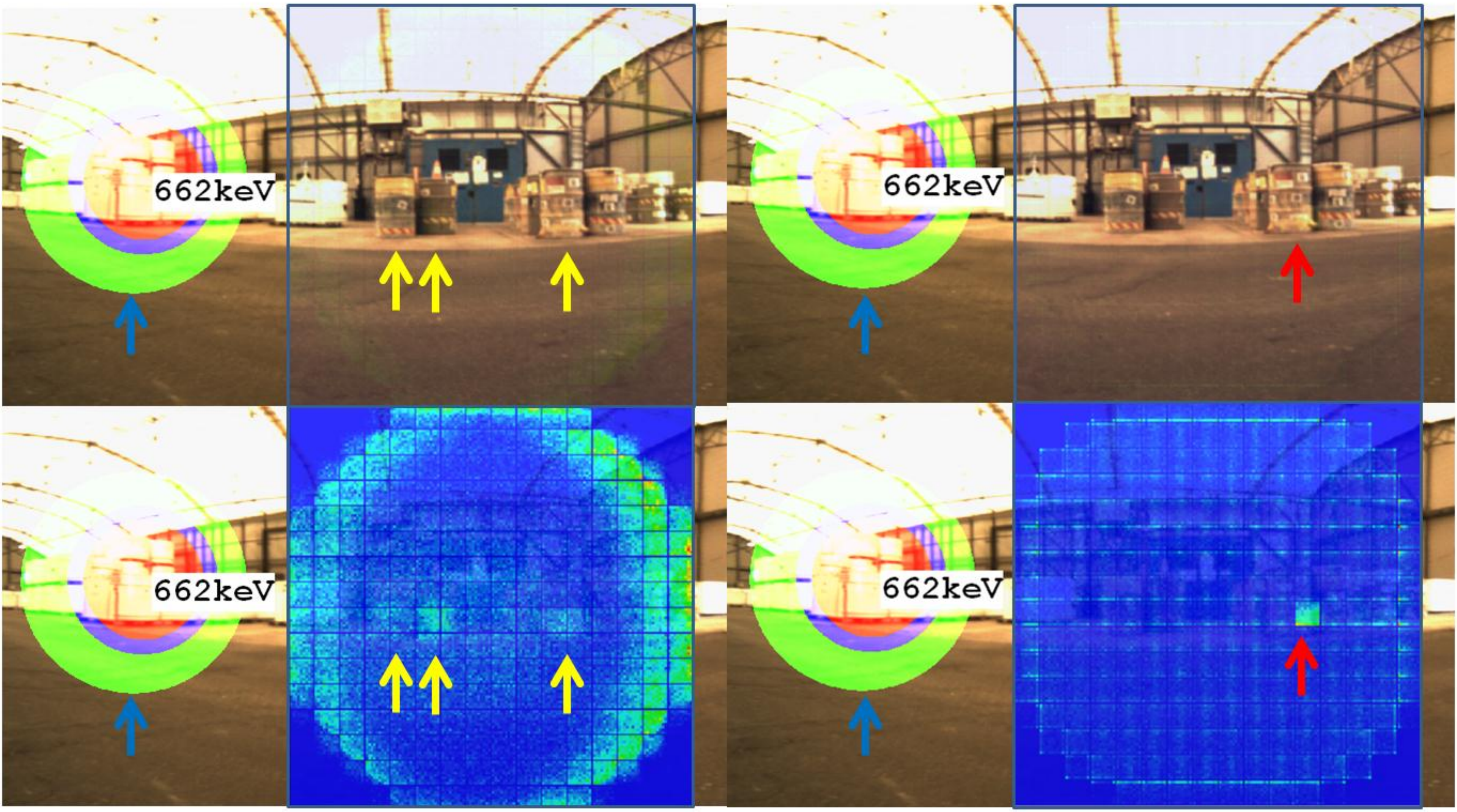
SRNL



^{137}Cs (662 keV) ^{237}Np (311 keV) ^{241}Am (59.5 keV)