Gamma Ray Imaging Detectors

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

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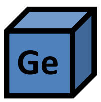
Collaboration with David Radford and Mitch Allmond at ORNL

- Physics challenge: hole-barrier contacts on germanium detectors
  - Lithium dead layer – volume loss – spectral artifacts
  - New "thin" Ag contact for Ge detectors
- Alpha particle data – thickness !!!!
- Important insights into contact physics –
  - Thick sputtered contacts
  - Thin evaporated contacts
- Modifications to fabrication of planar detectors (including GeGI)
  - Yield improvement
  - Example measurement

Basic Contact Physics – the need for barriers on HPGe detectors

HPGe

$|N_A - N_D| \sim 10^{10}$ /cm^3
μ ~ 4x10^4 cm^2/Vs (77 K)
ρ ~ 15 kΩ cm



1 cm^3, 1 V ~ 67 μA !!!!

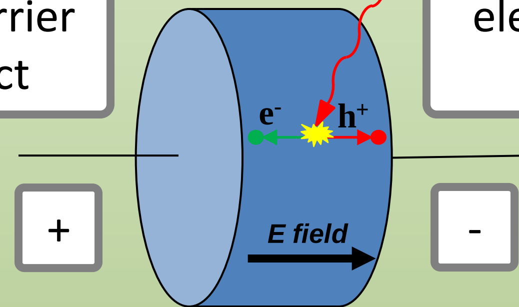
Resistivity is far too low

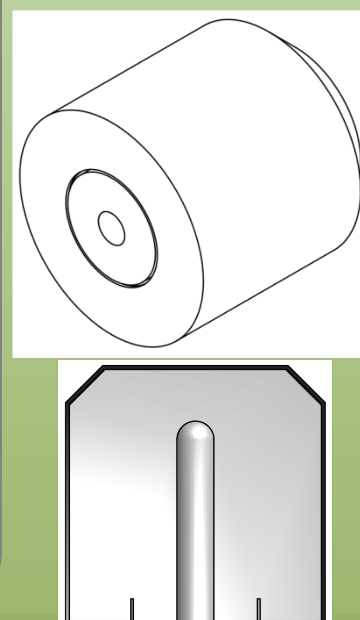
Contacts must form charge-injection barriers

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

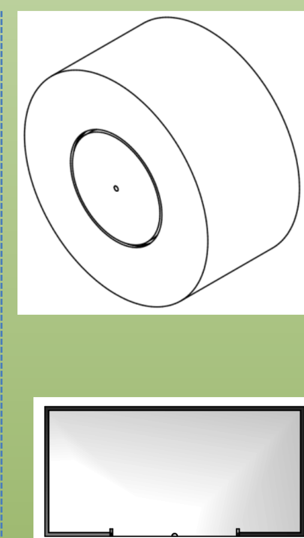
Hole-barrier contact

electron-barrier contact

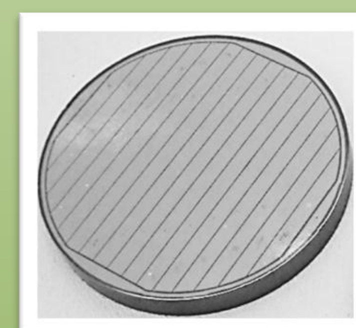




Coaxial Detector Li-diffused contact n+



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



Orthogonal Strip Detector α-Ge

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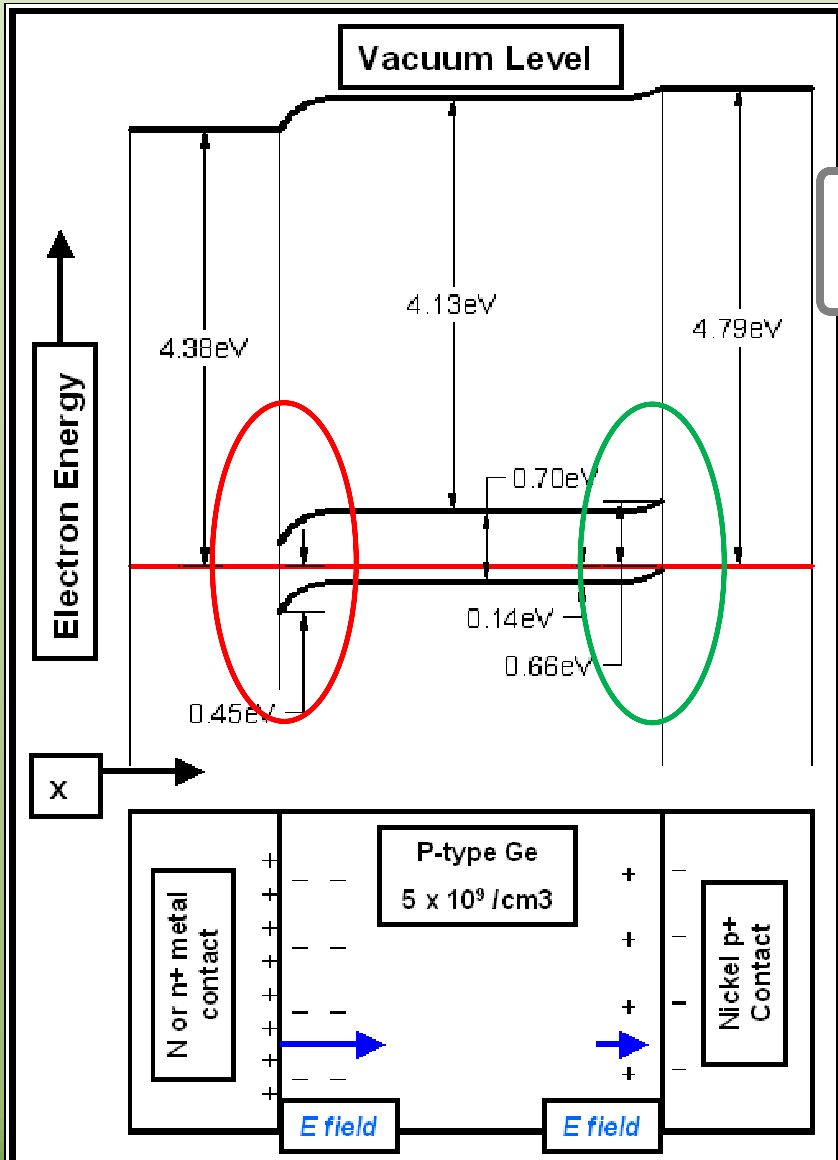
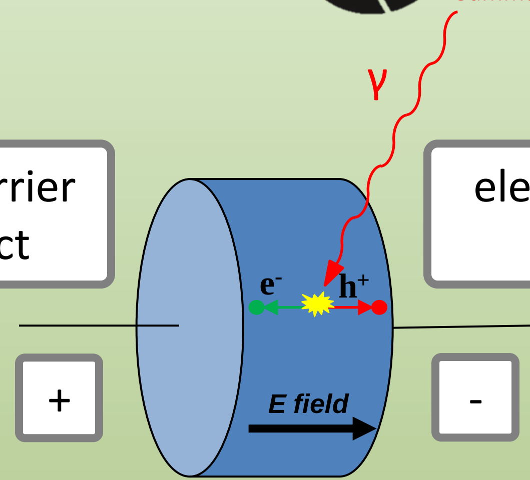


Hole-barrier contact

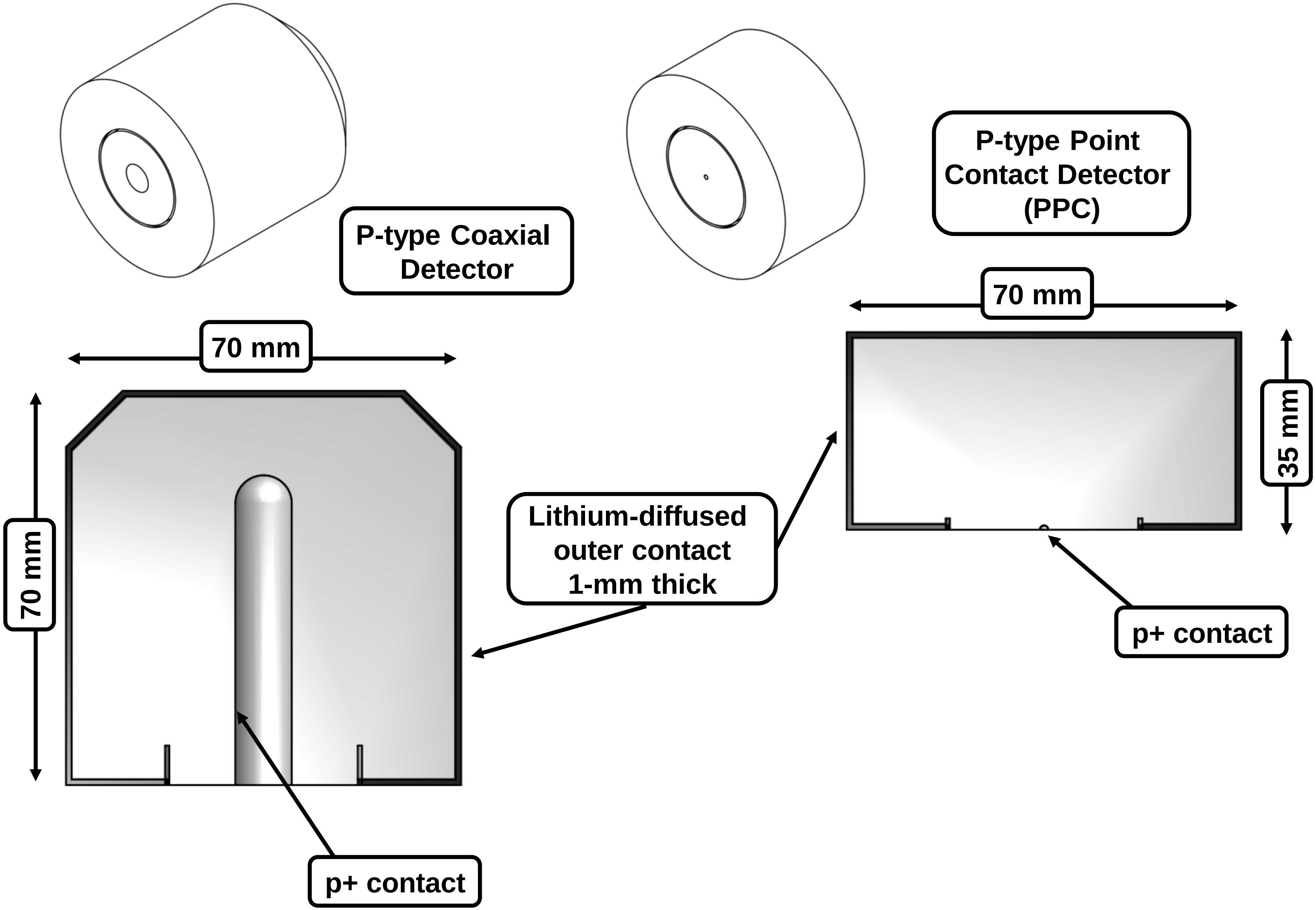


electron-barrier contact

Li diffusion, α-Ge
α-Si (O_X)
P implant
(anneal), Y(O_X),
Ag (new)

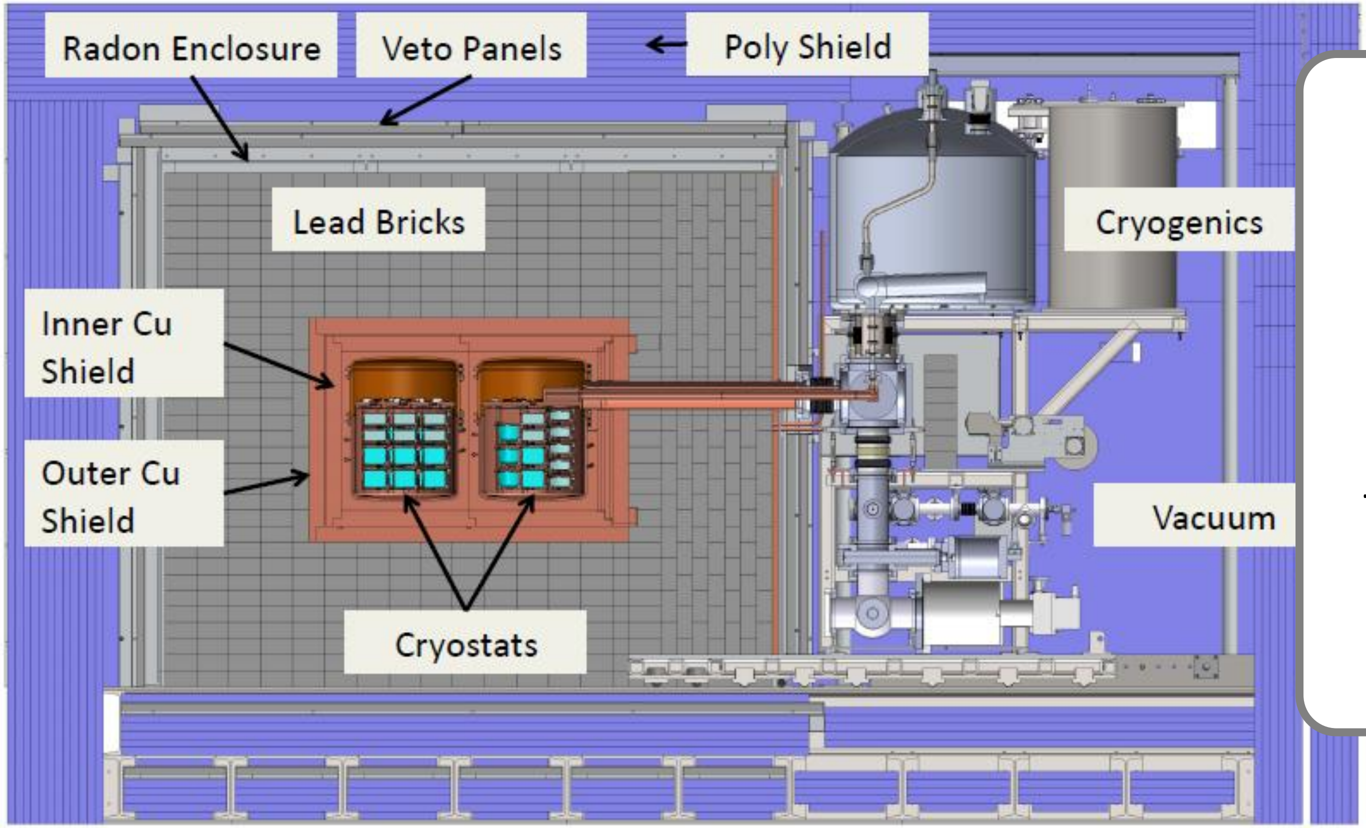
Many options: B, Ni, Cr, Pt, Pd, Au, ..

Lithium-diffused contact works but…



7-8 % of the detector is Li dead layer

The MAJORANA DEMONSTRATOR



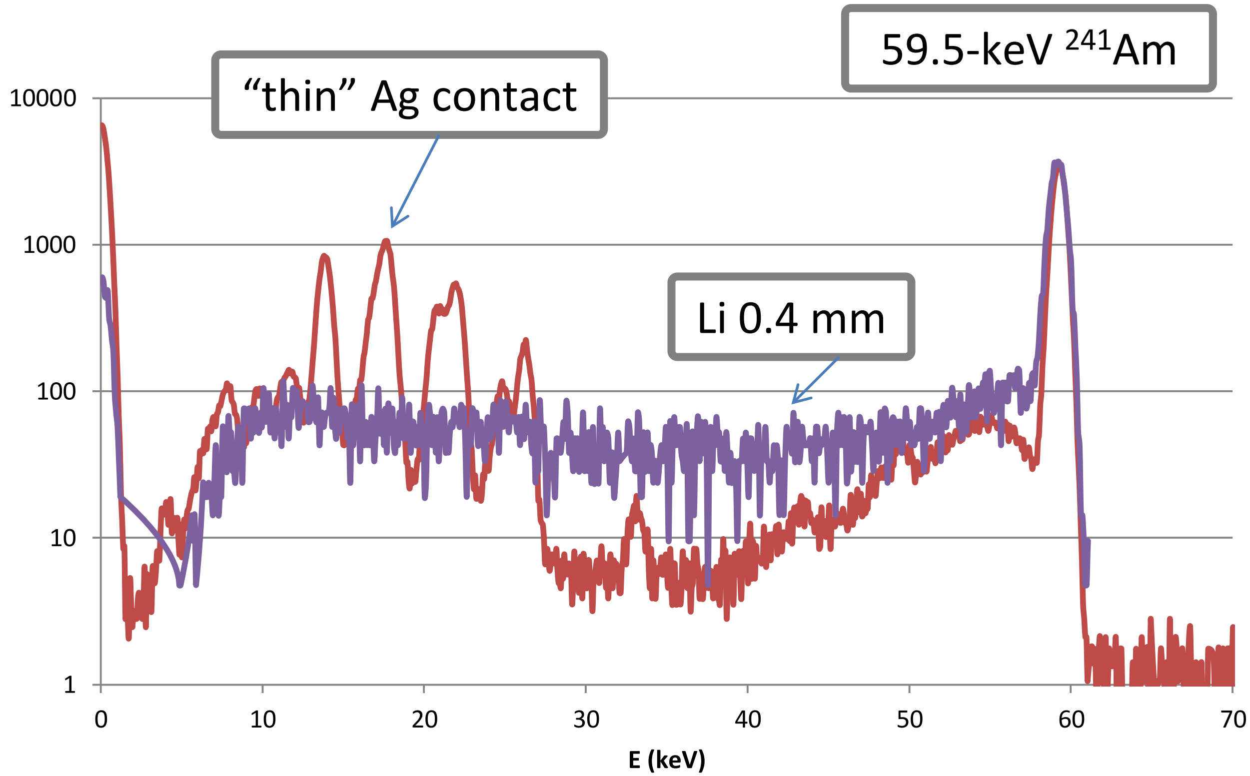
A large array:

Goal: 1000 kg ^{76}Ge

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

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

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



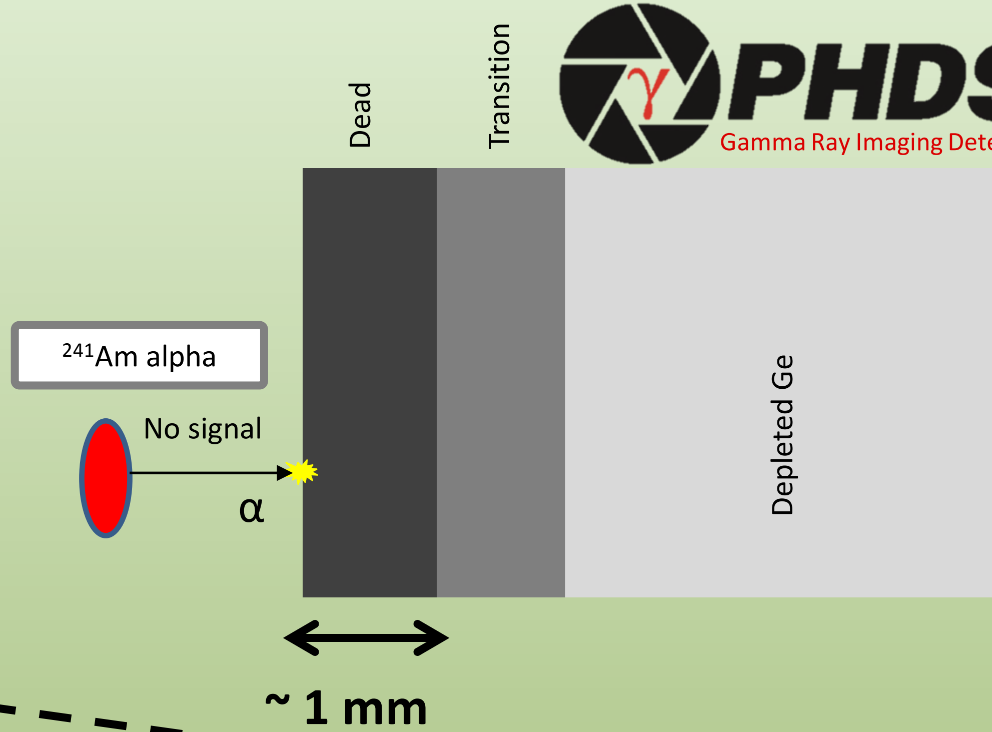
Thick lithium-diffused dead layer causes spectral artifacts

Lithium contact causes:

1. Volume loss
2. Spectral artifacts

However:

The lithium contact has the single redeeming quality that it stops alphas (5 MeV) in 20 μm.



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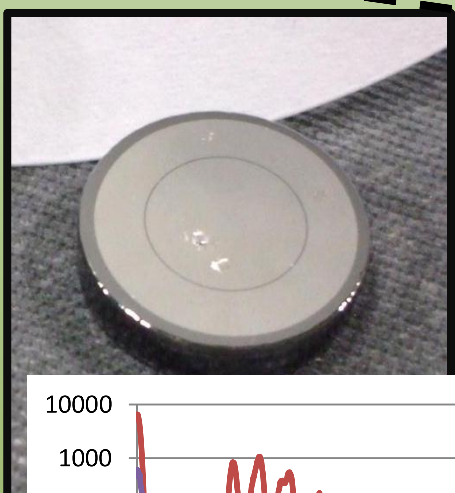

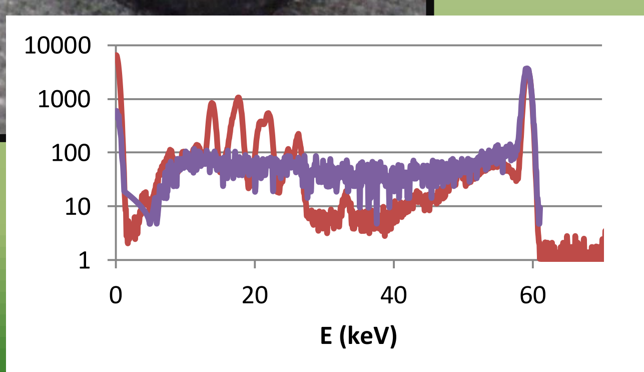

Ag contact

- Forms hole-barrier!
- Good resolution
- Good segmentation
  - 100-μm gap
- Thin contact
  - Photons

Evaluate Ag contact with alpha particles

- **How thick is Ag?**
- **Is there a way to identify alphas to reduce background?**

MJ1 Cryostat

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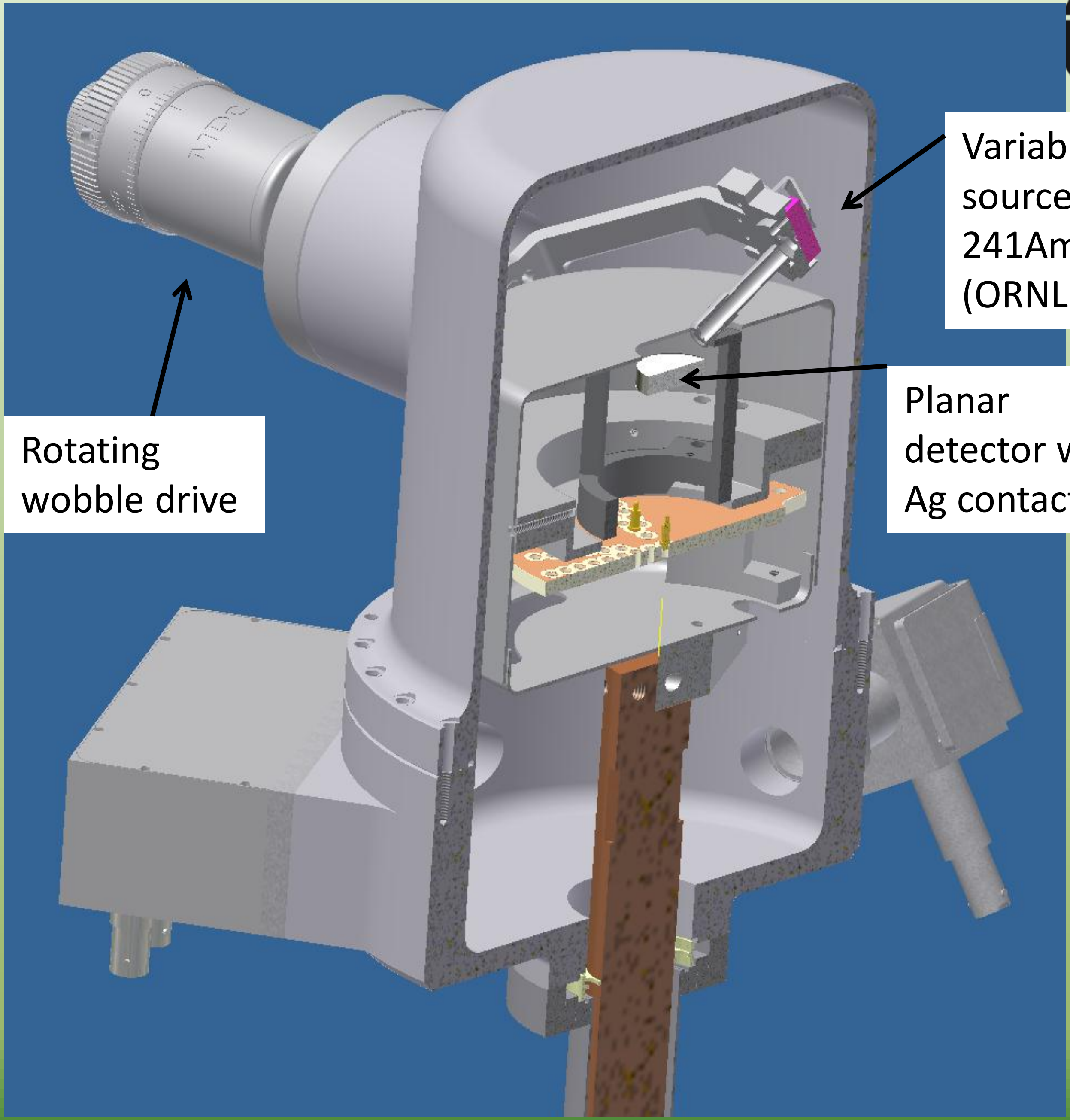
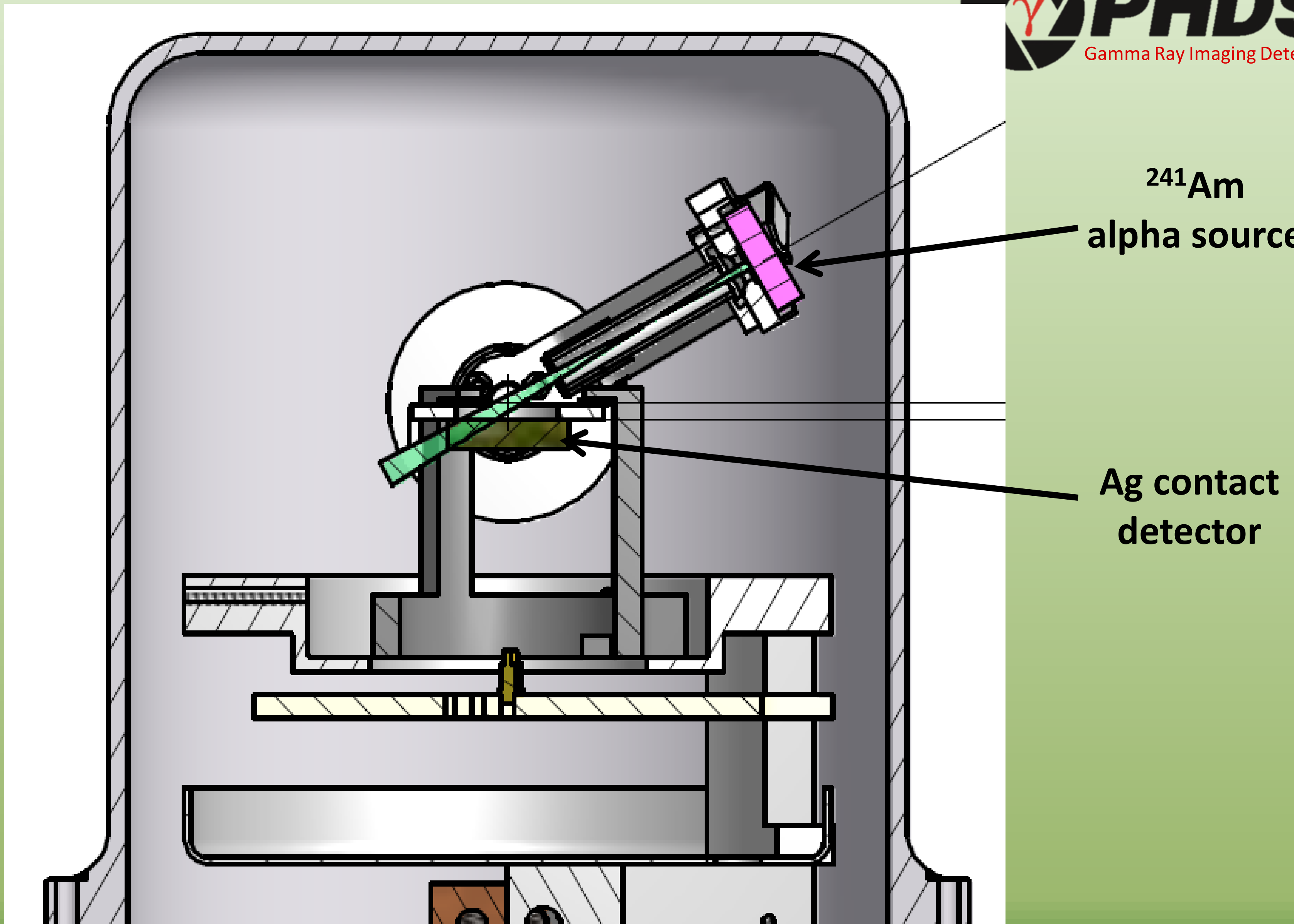
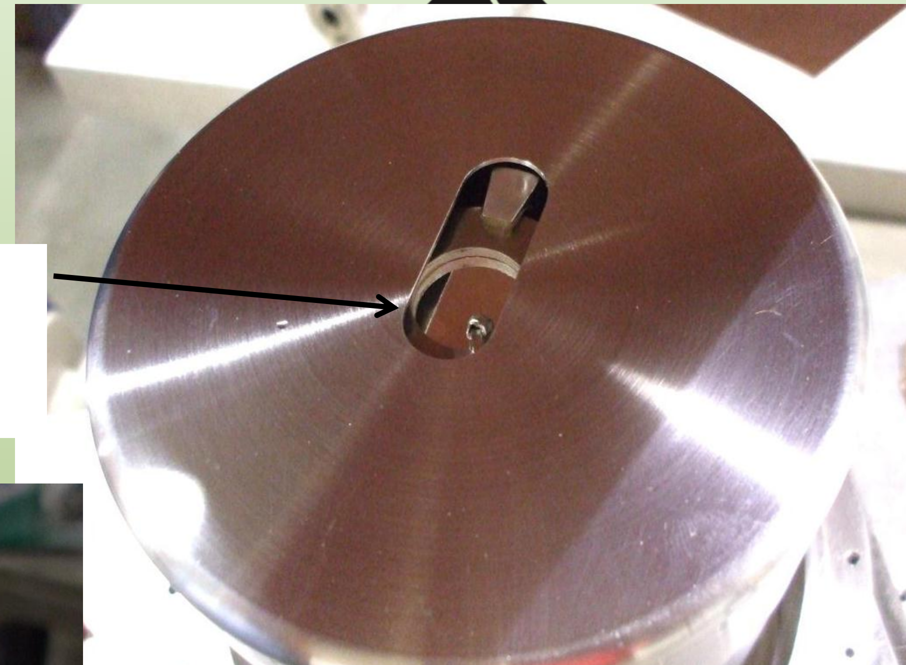


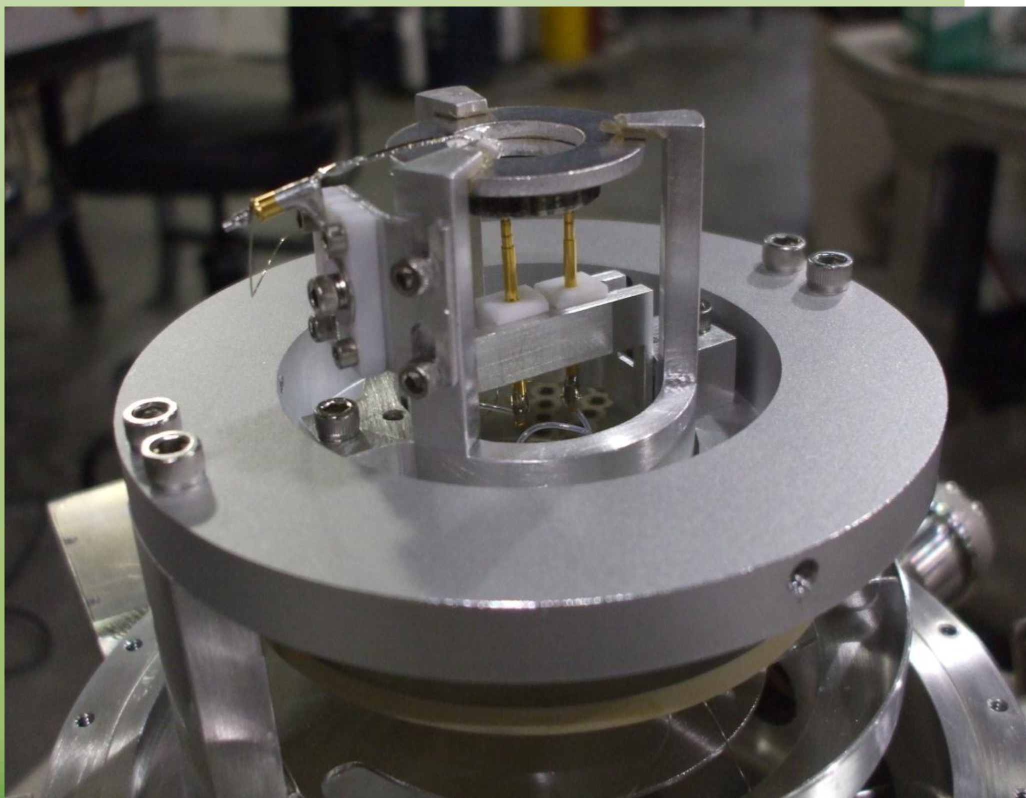
Focus on evaluating the Ag contact on small planar detectors.


^{241}Am
alpha source
Ag contact
detector

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





First Look at Ag contact

Absolute Energy calibration

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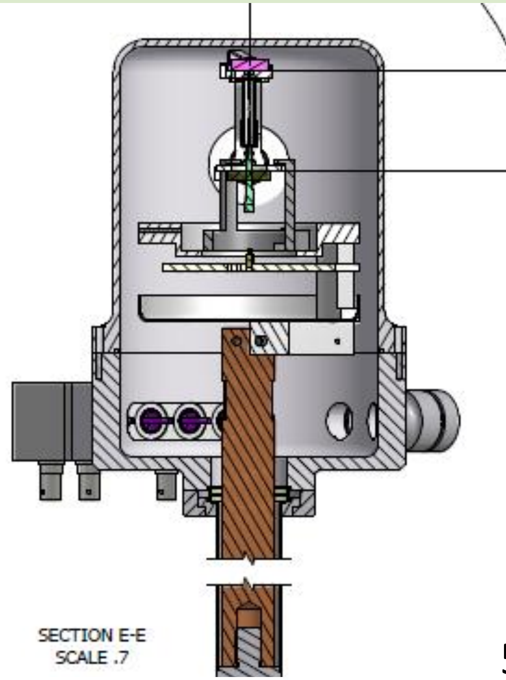
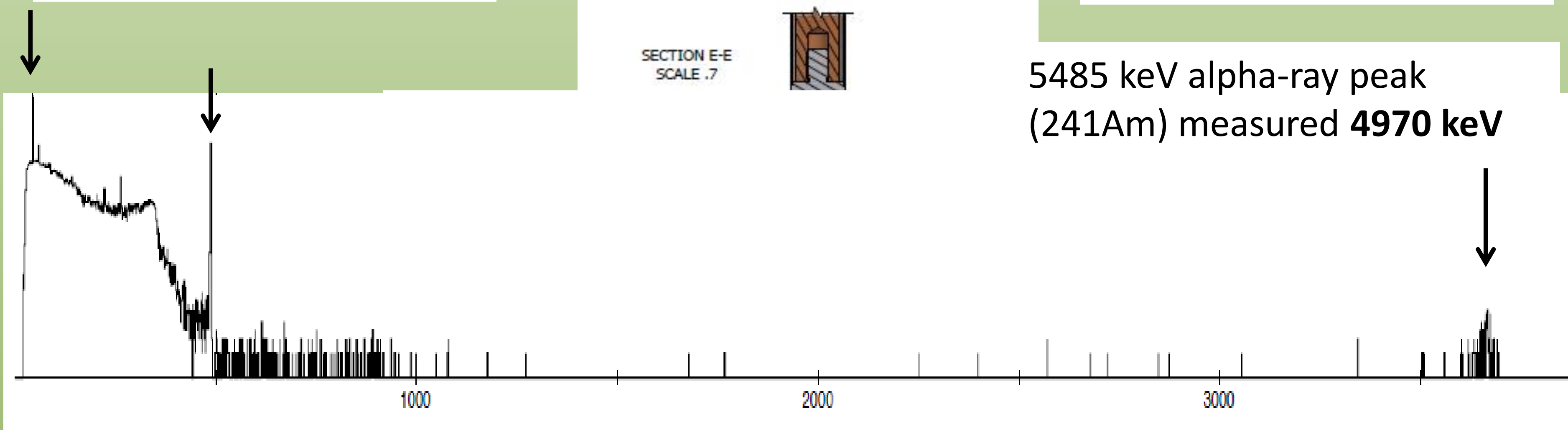


0° incidence

P-type HPGe 5 mm thick
V_{depl} = + 130 V (9.2×10^{9} /cm³)
V_{op} = + 600 V

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**

Peak shift vs. angle of incidence

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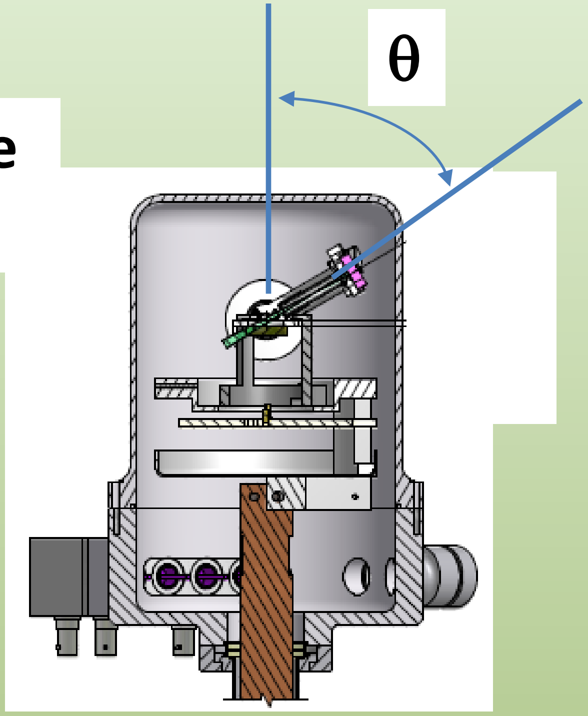
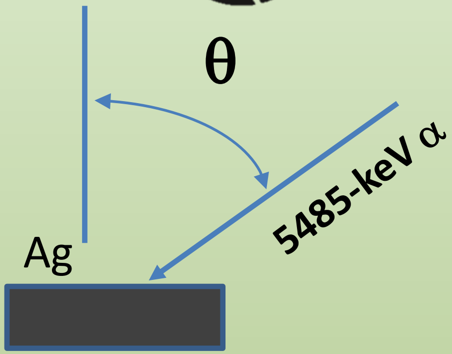
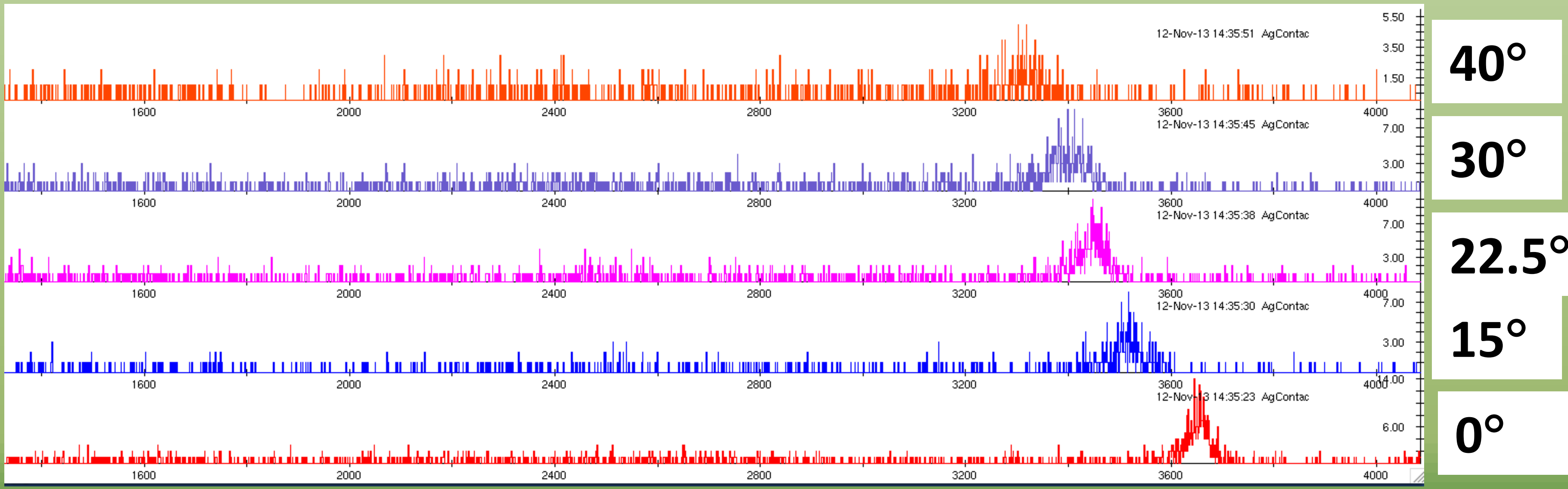
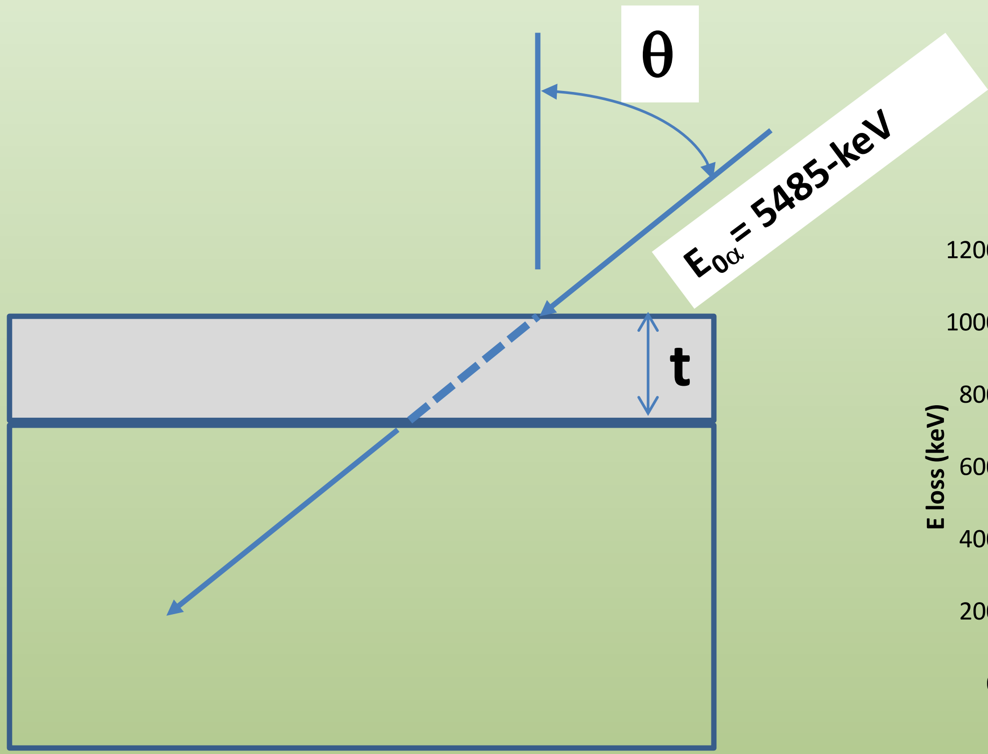
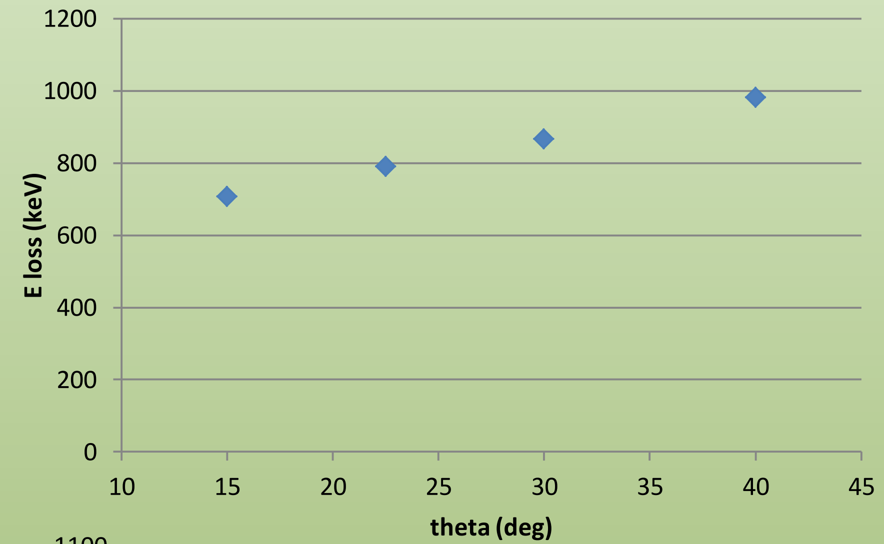


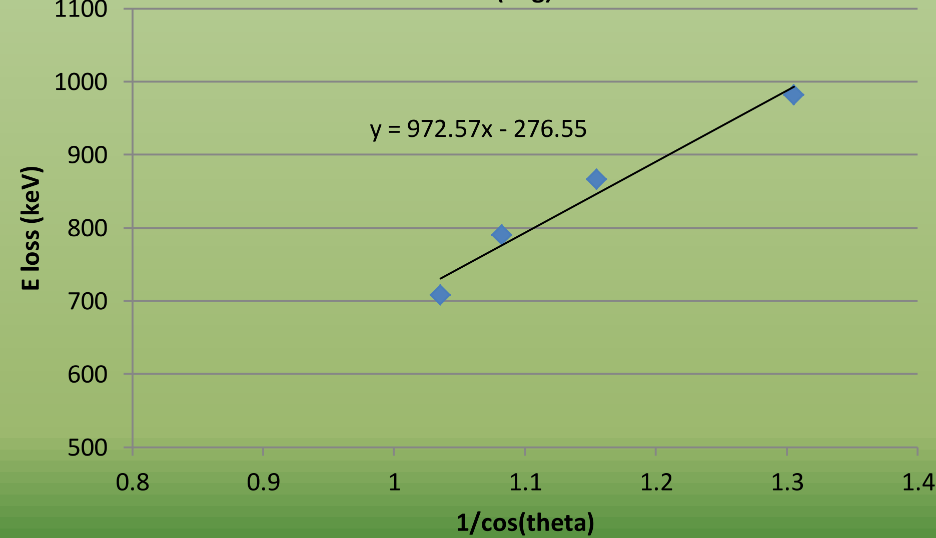




$$E_{loss} = (dE/dx)\ \mathbf{t}/\cos(\theta)$$

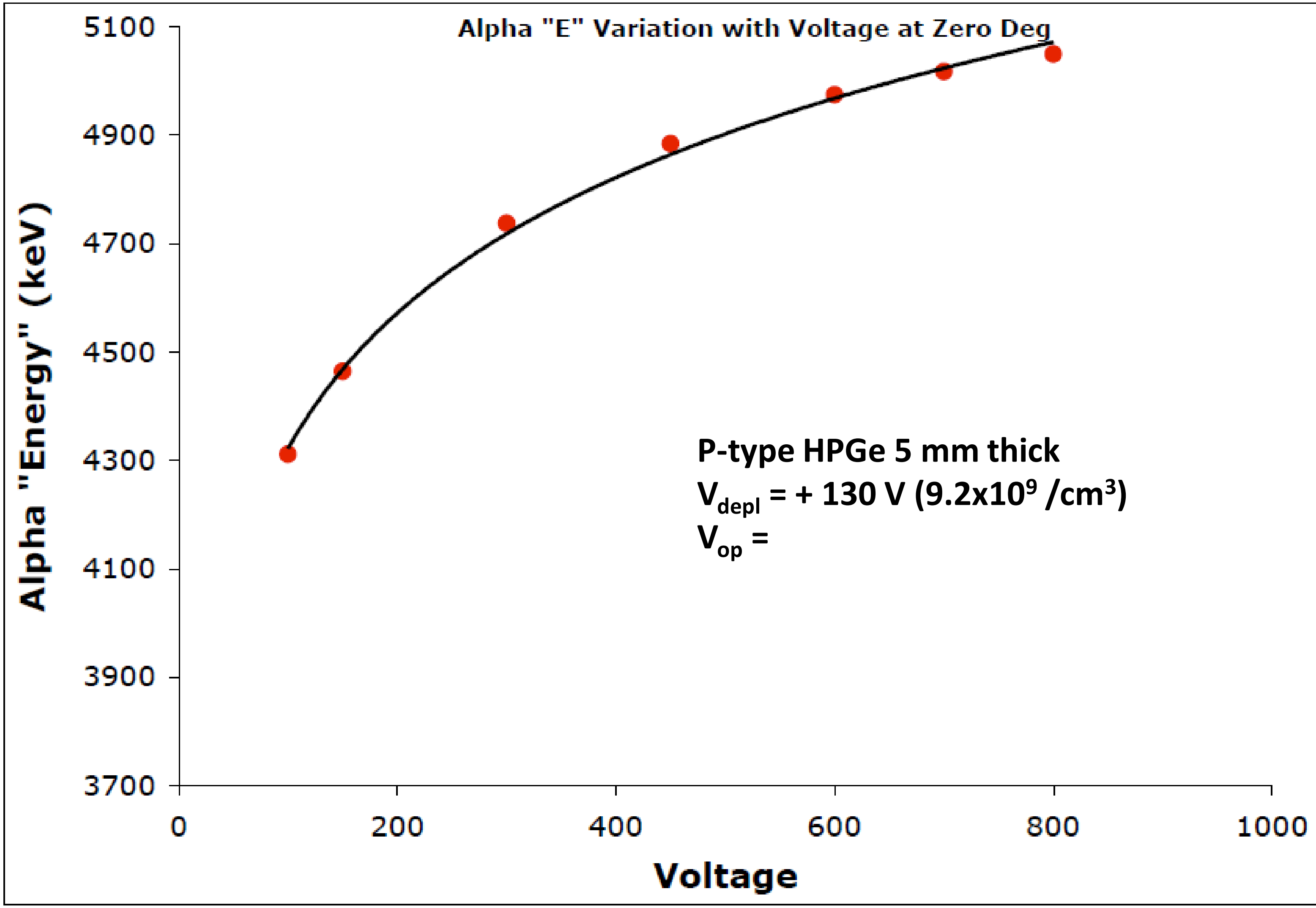




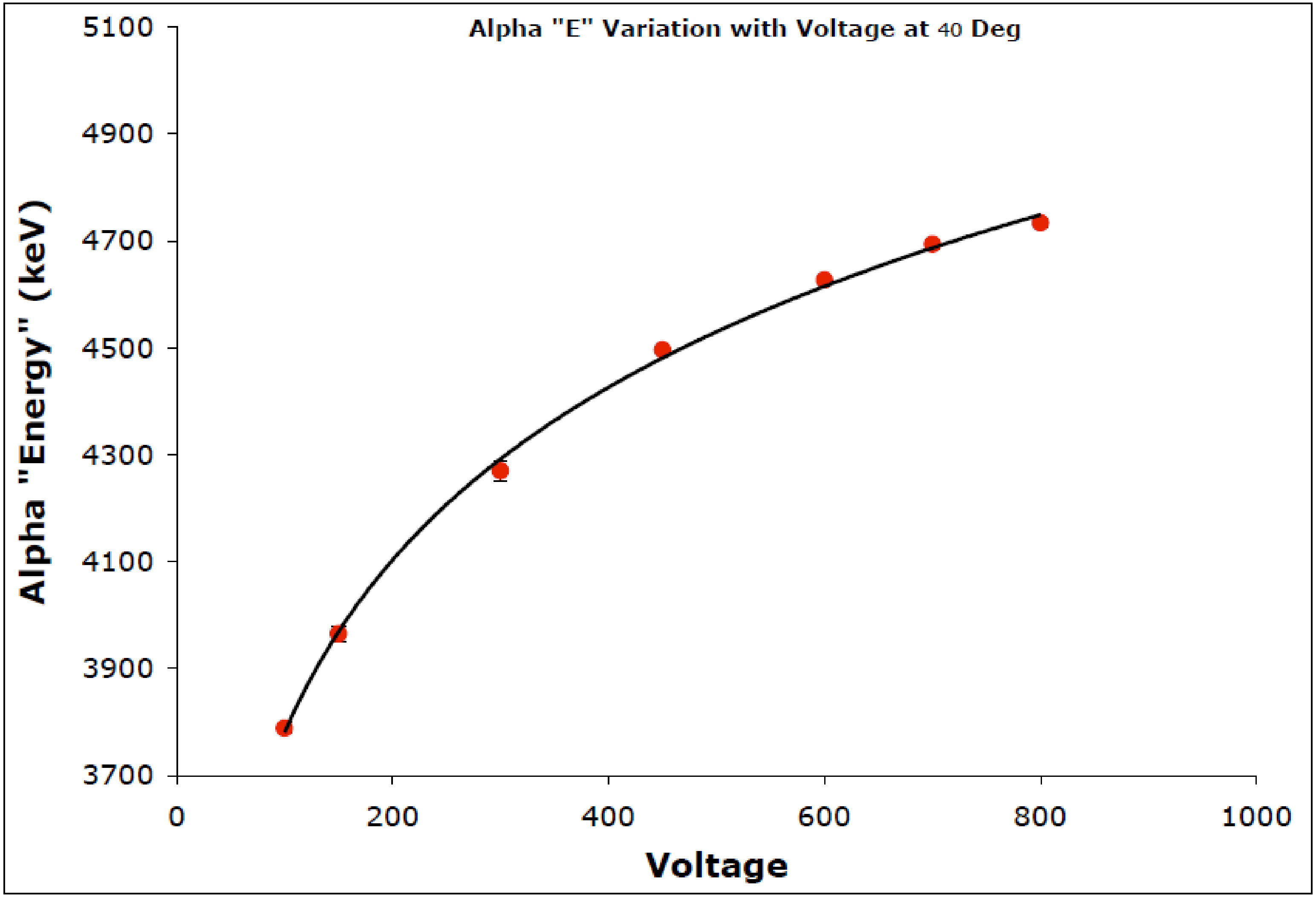


t = 973 keV/0.020 keV/A
= 48,650 A = **4.9 μm**

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°



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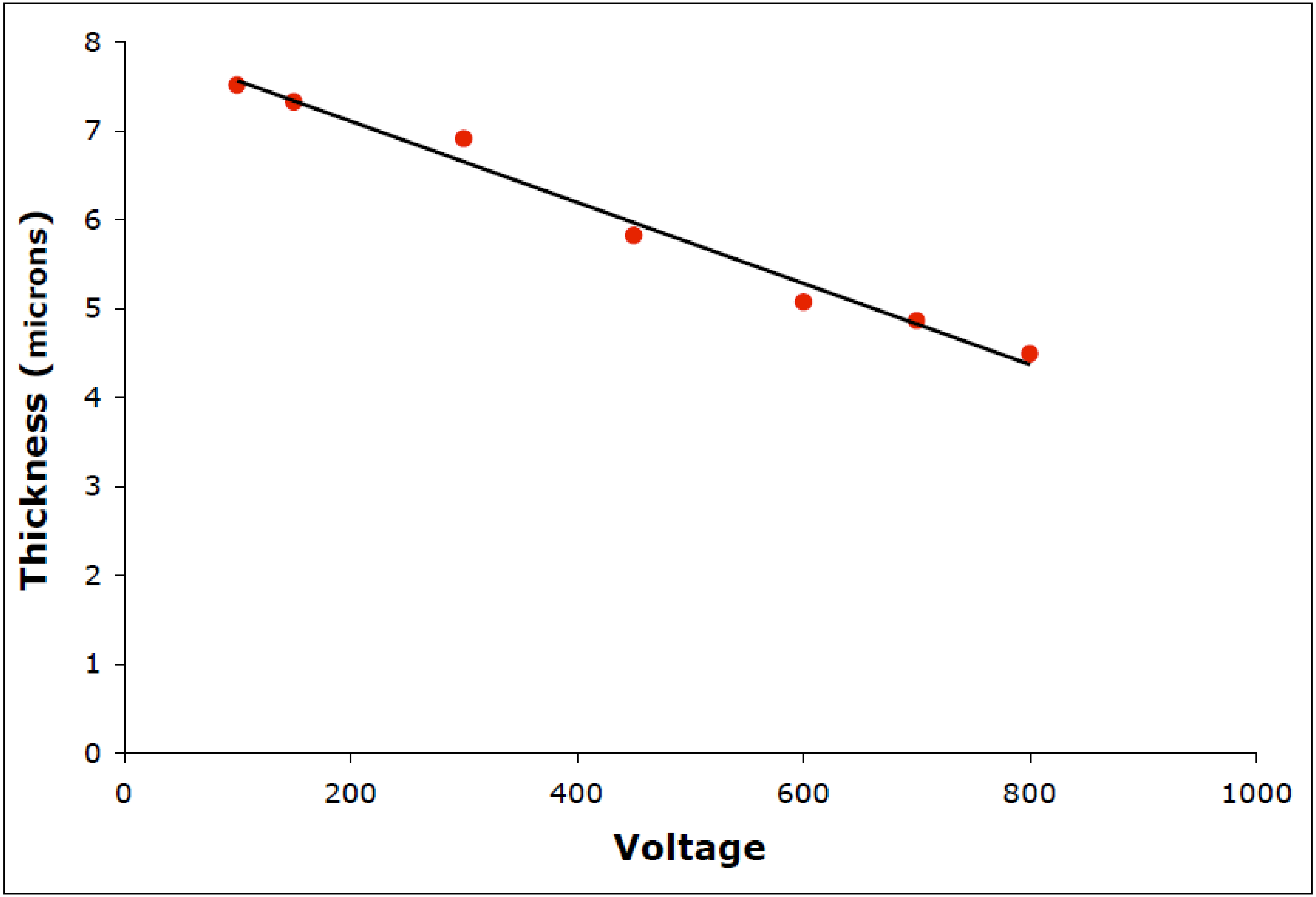
Voltage



Thickness (microns)
Voltage
0
1
2
3
4
5
6
7
8
0
200
400
600
800
1000

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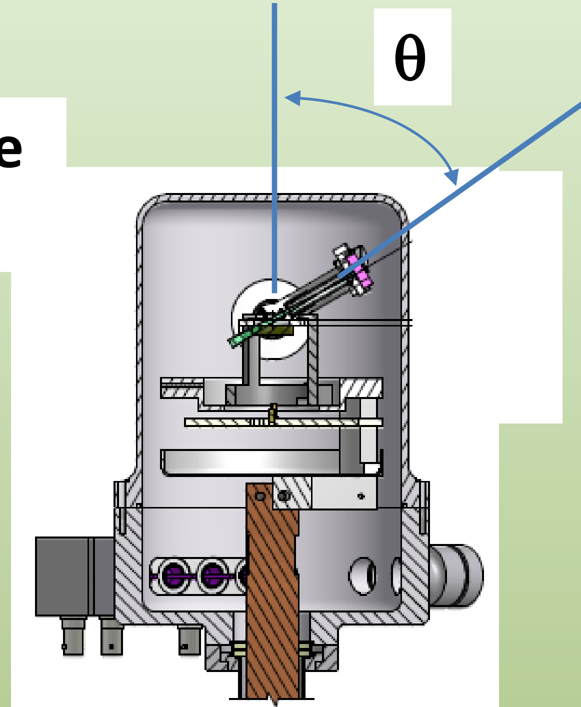
As measured by Alpha particles:

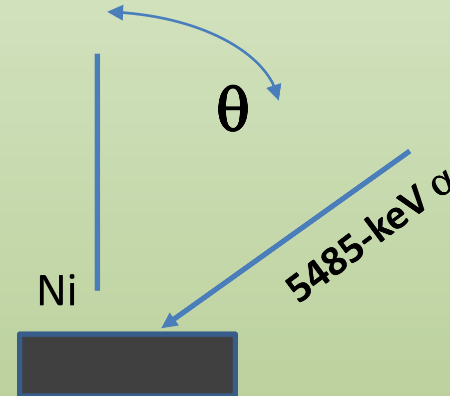
1. A contact is 4-8 microns thick.

2. The dead layer thickness is bias voltage (electric field) dependent.

3. True for **Ag** and **αGe** contacts, both + and – polarity bias.

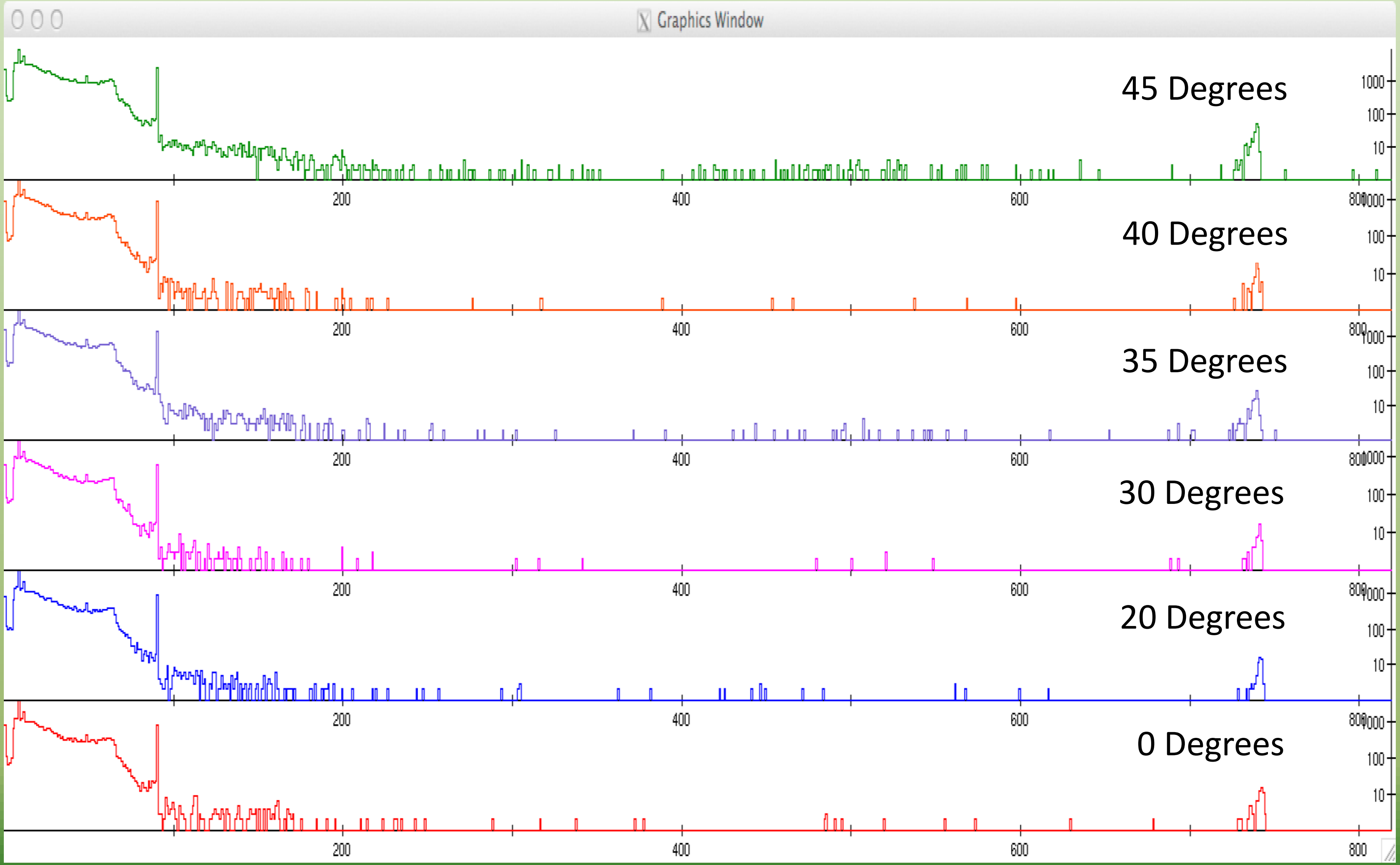
Peak shift vs. angle of incidence





P-type HPGe 5 mm thick
V_{depl} = - 100 V (9.2x10^9 /cm^3)
V_{op} = - 1000 V

Ni Detector Spectra -1000 V



Ni Detector Spectra -1000 V

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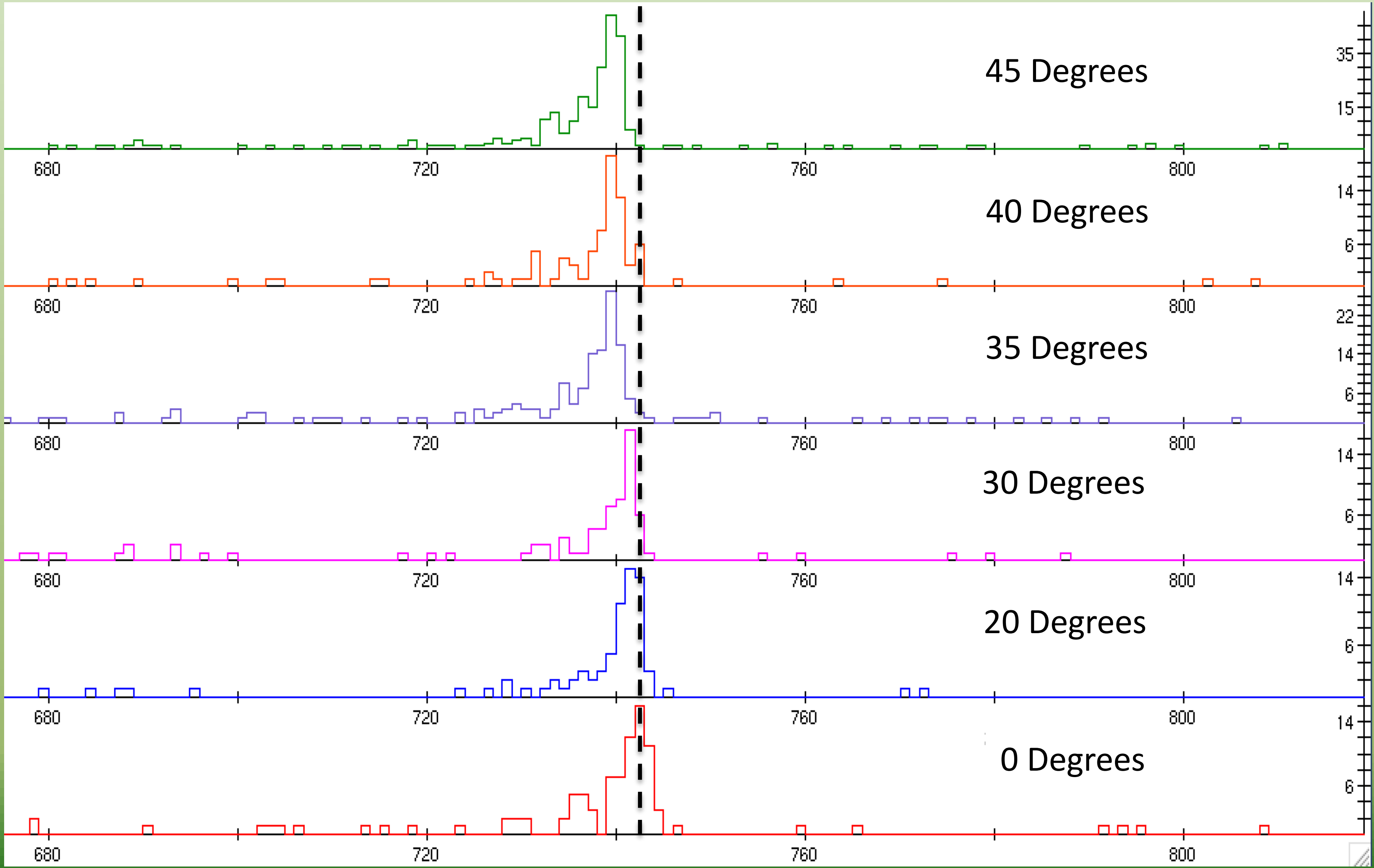

Ni Detector Thickness -1000 V

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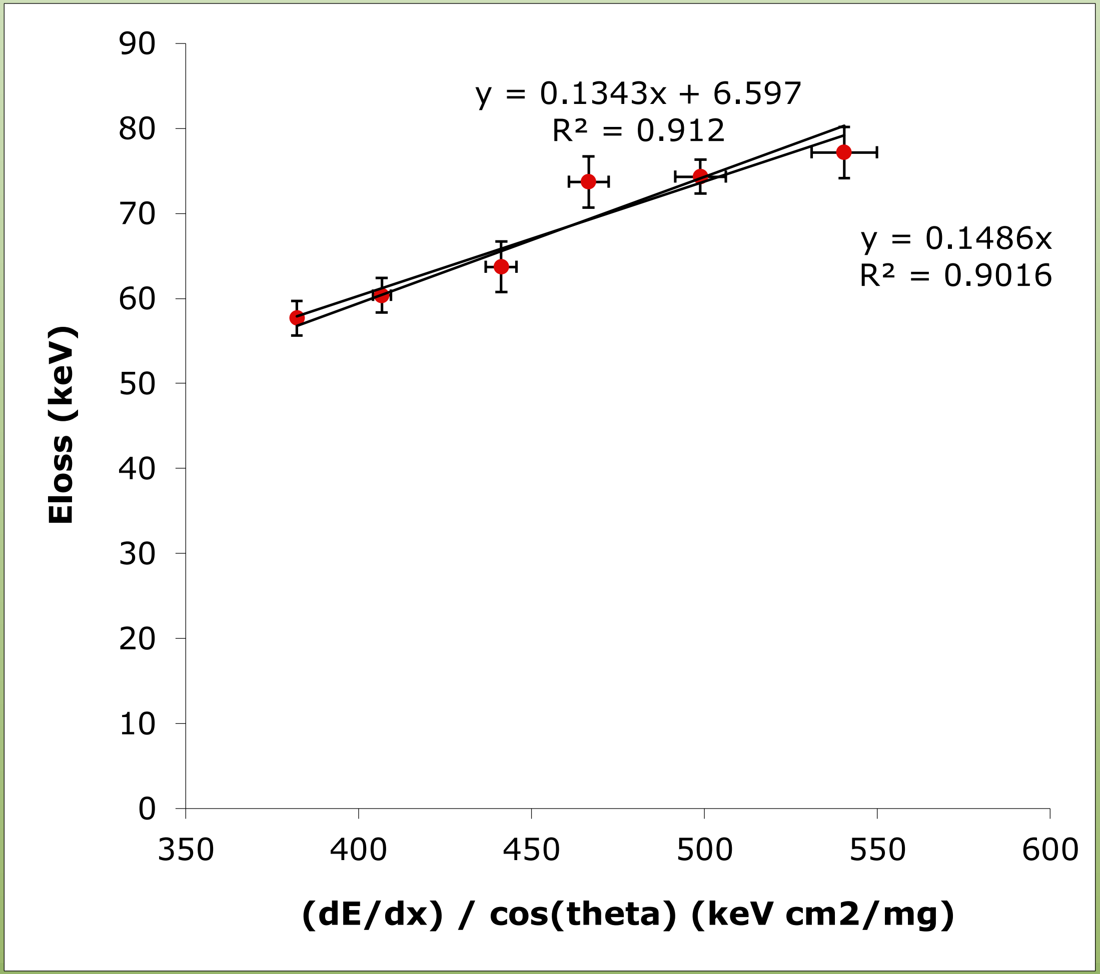
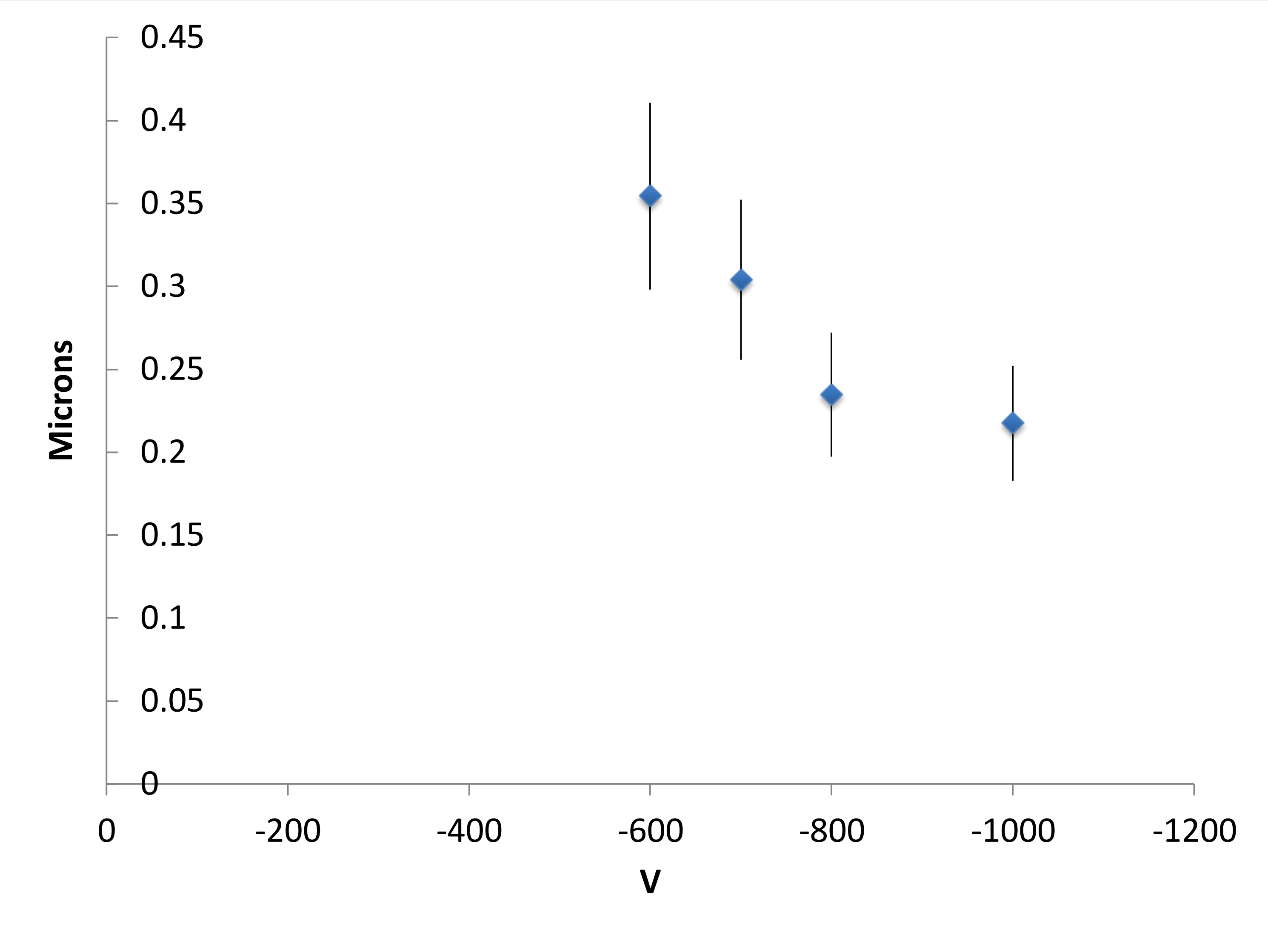
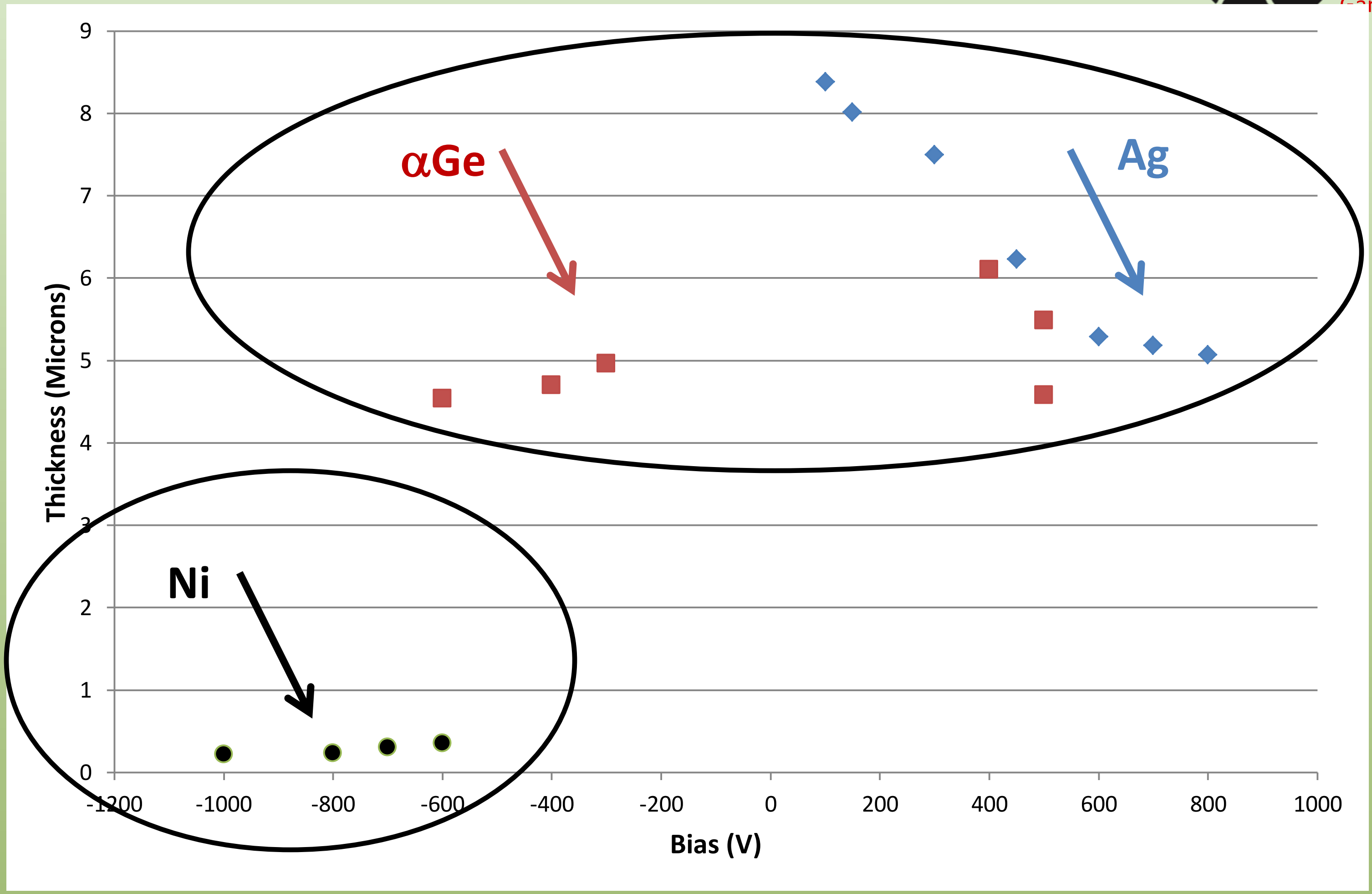


Thickness (mg/cm^2) = slope
Thickness (microns) = slope * 1.88

Ni dead layer vs. bias voltage



Summary



The Ag and αG contacts are very thick, microns !!

– Mechanism ?

Search Application

Chicago **Radioactive Threat!**

What is it?

Where is it?

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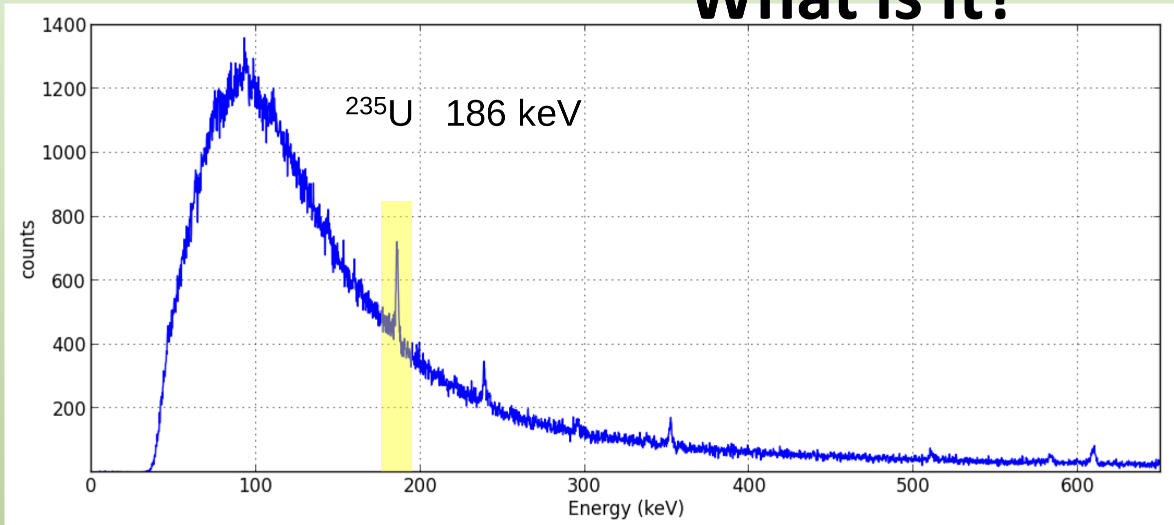
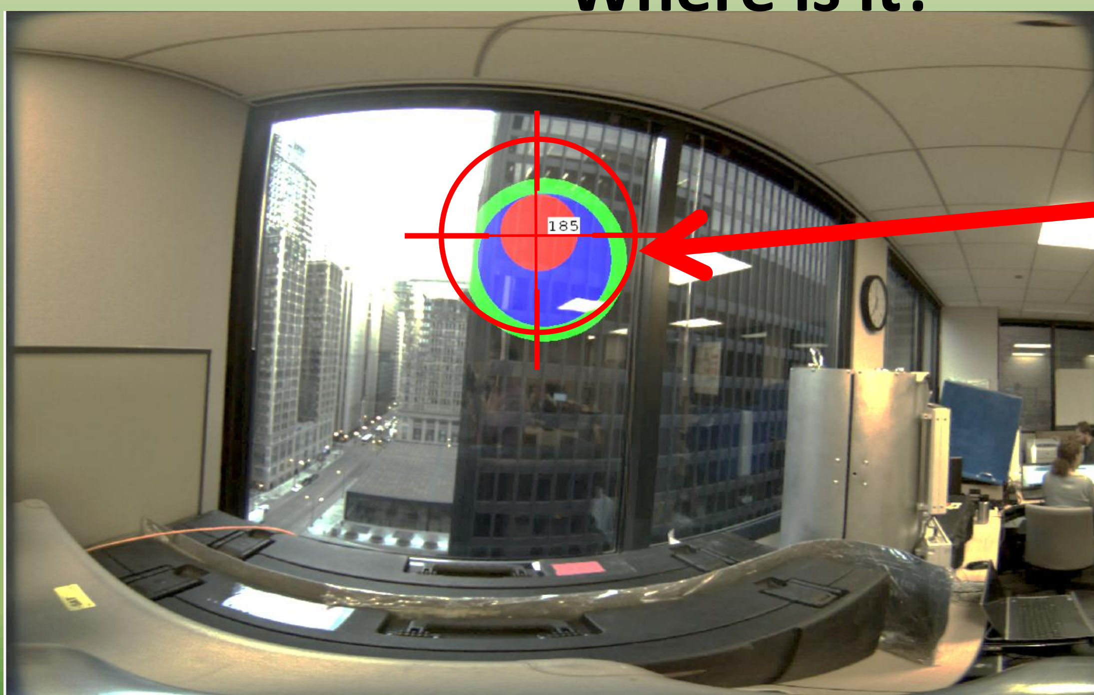
What is it?



HEU – ^{235}U – Weapons Grade Uranium !

Where is it?



In that room, on the 13th floor of the Kluczynski Building

Distance: 28 m
Spectral detection: 15 min (8 σ)
Image detection: 39 min (3 σ)

Thank you