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

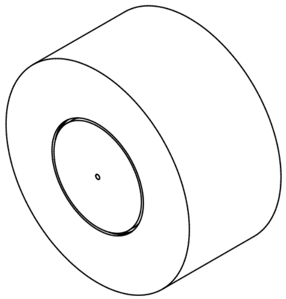
DE-SC0006348 Ethan Hull PI

8/6/2012-8/7/2014

New thin-contact technologies have been developed for germanium-semiconductor detectors. Sputter-deposited contacts have been demonstrated to form reliable, rugged, thin, and easily segmented hole- and electron-barrier contacts with good fabrication yield on small planar germanium detectors. Detectors fabricated with these contacts exhibit low noise and excellent gamma-ray spectroscopy. The contact fabrication is being modified to accommodate the fabrication of p-type point contact detectors for low-background counting experiments. The thickness of the contact is being evaluated using alpha particles.

Collaboration with David Radford at ORNL

- Physics of the hole-barrier contacts on germanium detectors – p-type surfaces
- Advantages of a thin contact that can be segmented for low background counting
  - Poor low-energy spectroscopy (Ge(Li) 1960s)
  - Slow pulses from the lithium transition region (David Radford)
  - Dead material loss of volume
- Detector fabrication development with thin contacts
  - Photolithography modifications
  - Detector results
  - Modified cryostat including alpha source holder



Basic Contact Physics – the need for barriers on HPGe detectors

HPGe

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

$\rho \sim 15$ kΩ cm

1 cm^3, 1 V ~ 67 µA !!!!

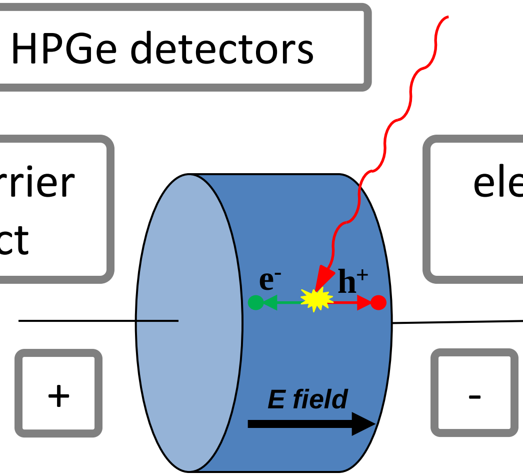
Resistivity is far too low

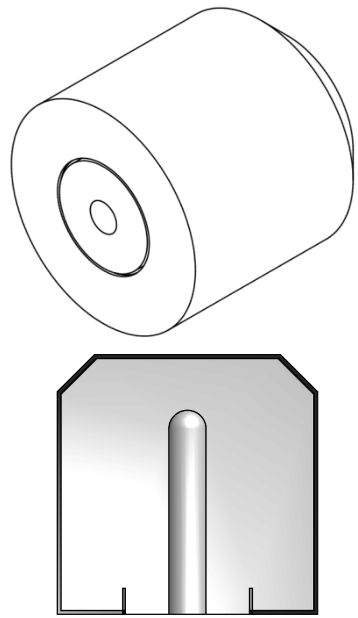
Contacts must form charge-injection barriers

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

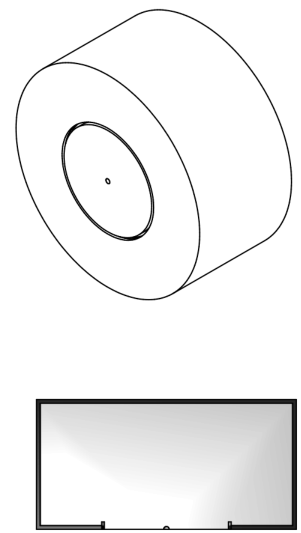
Hole-barrier contact

electron-barrier contact

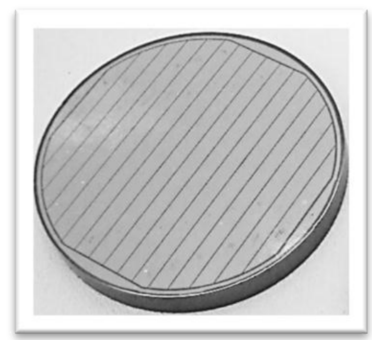




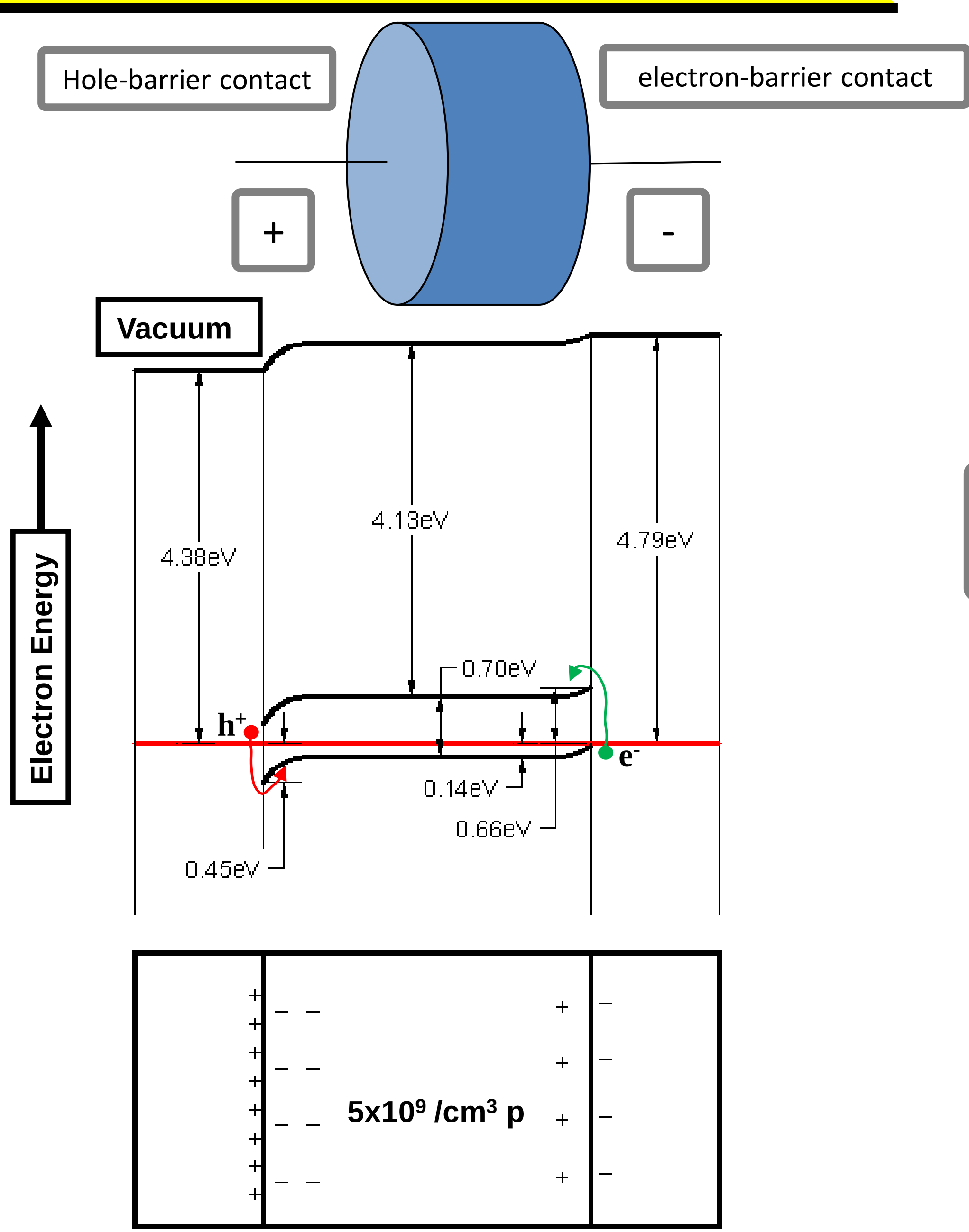
Coaxial Detector Li-diffused contact n+



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

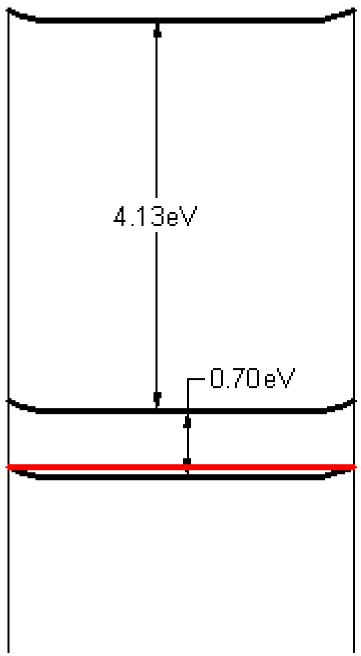


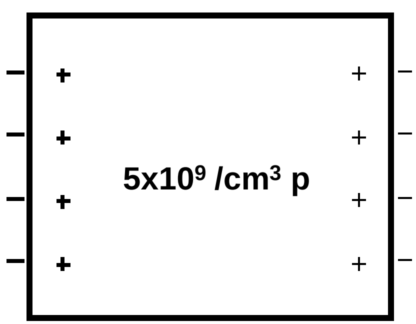
Orthogonal Strip Detector α-Ge (2nd talk)



Ideal contact formation

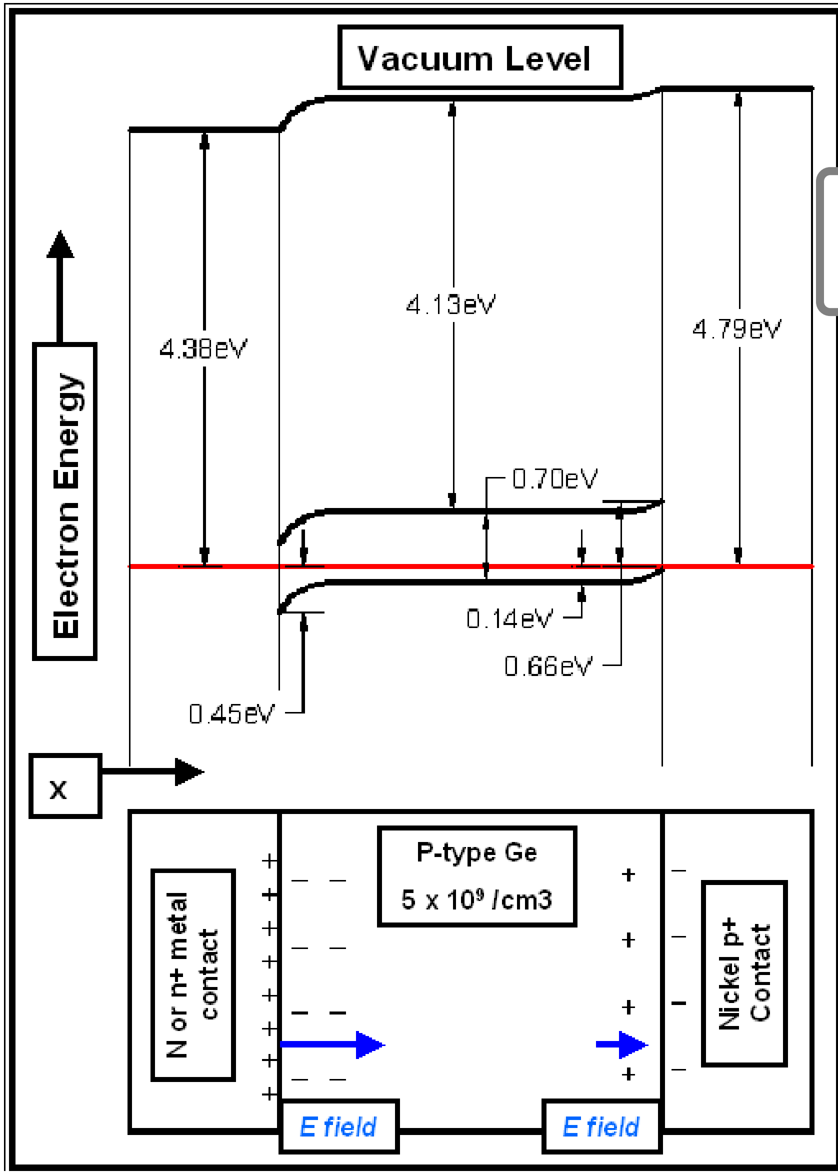
However…



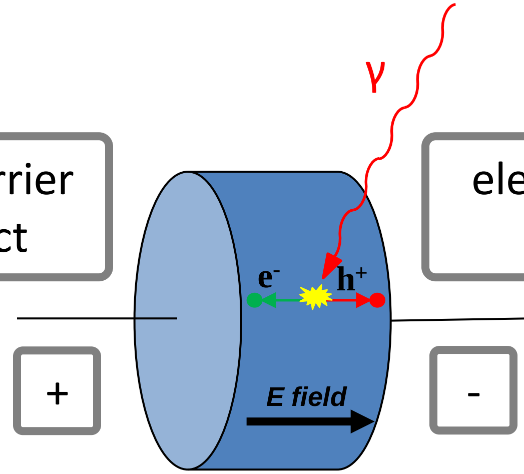


Damage is p-type (an acceptor state) in crystalline Ge

- 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



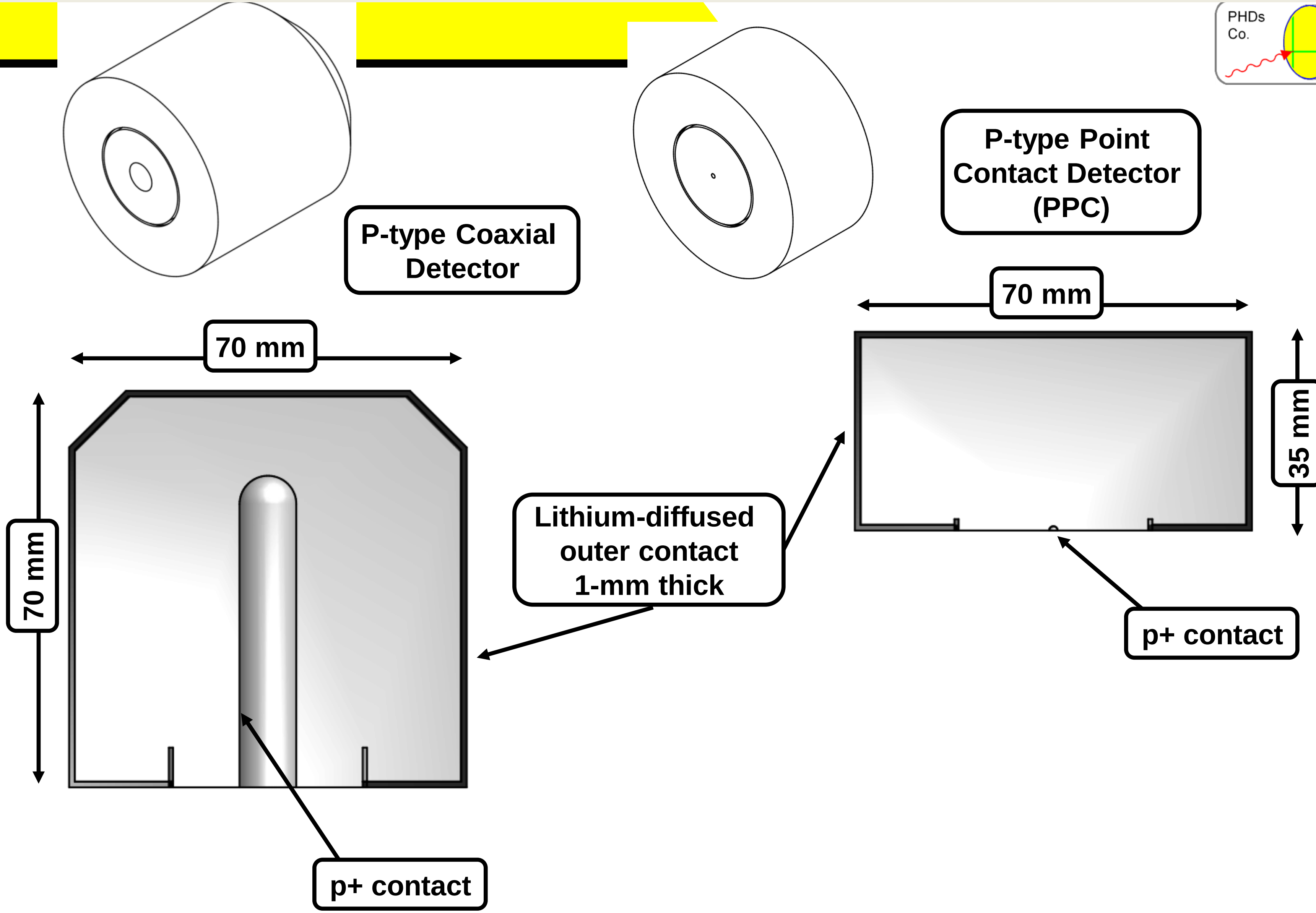
Hole-barrier contact



electron-barrier contact

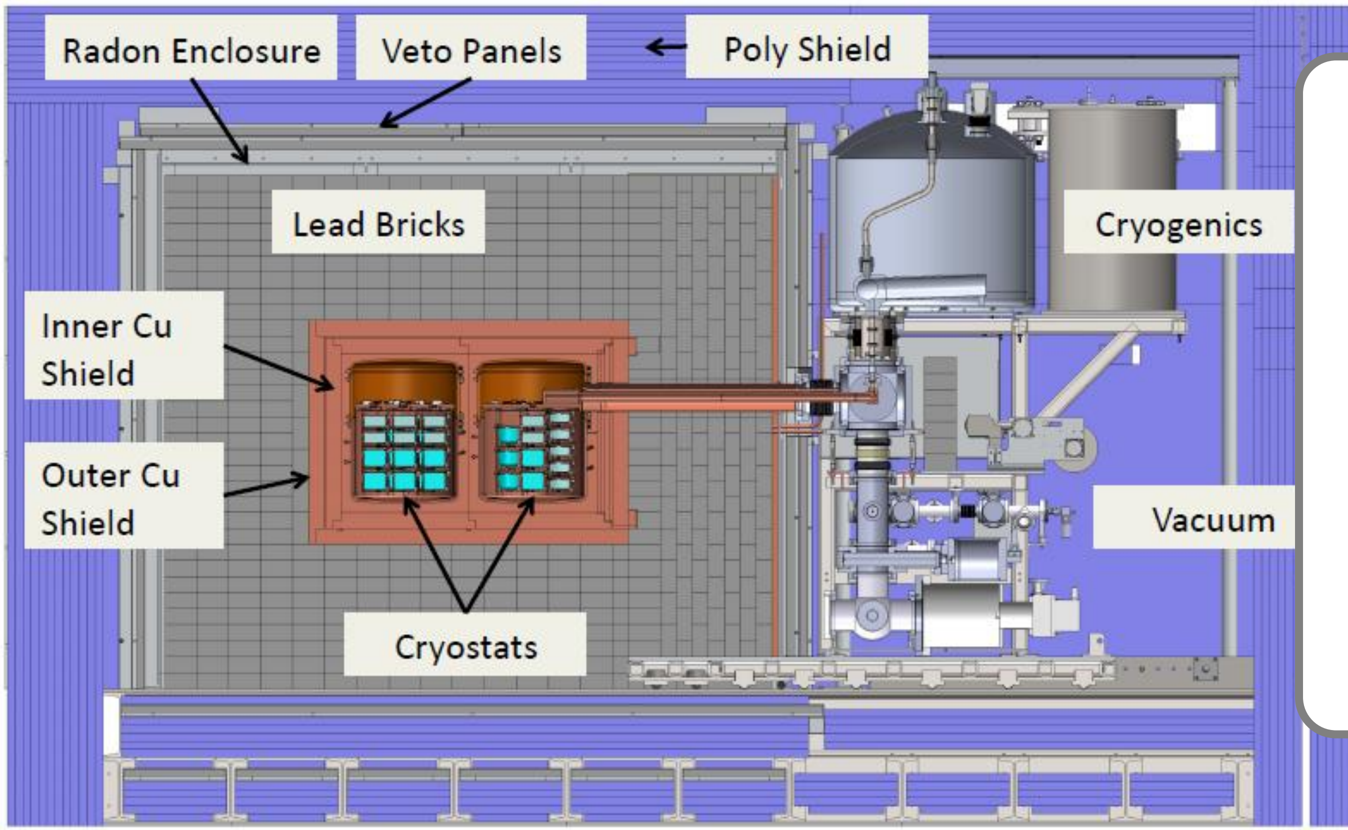
Li diffusion, α-Ge
α-Si (O_X)
P implant
(anneal), Y(O_X)

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



7-8 % of the detector is Li dead layer

The MAJORANA DEMONSTRATOR



Majorana

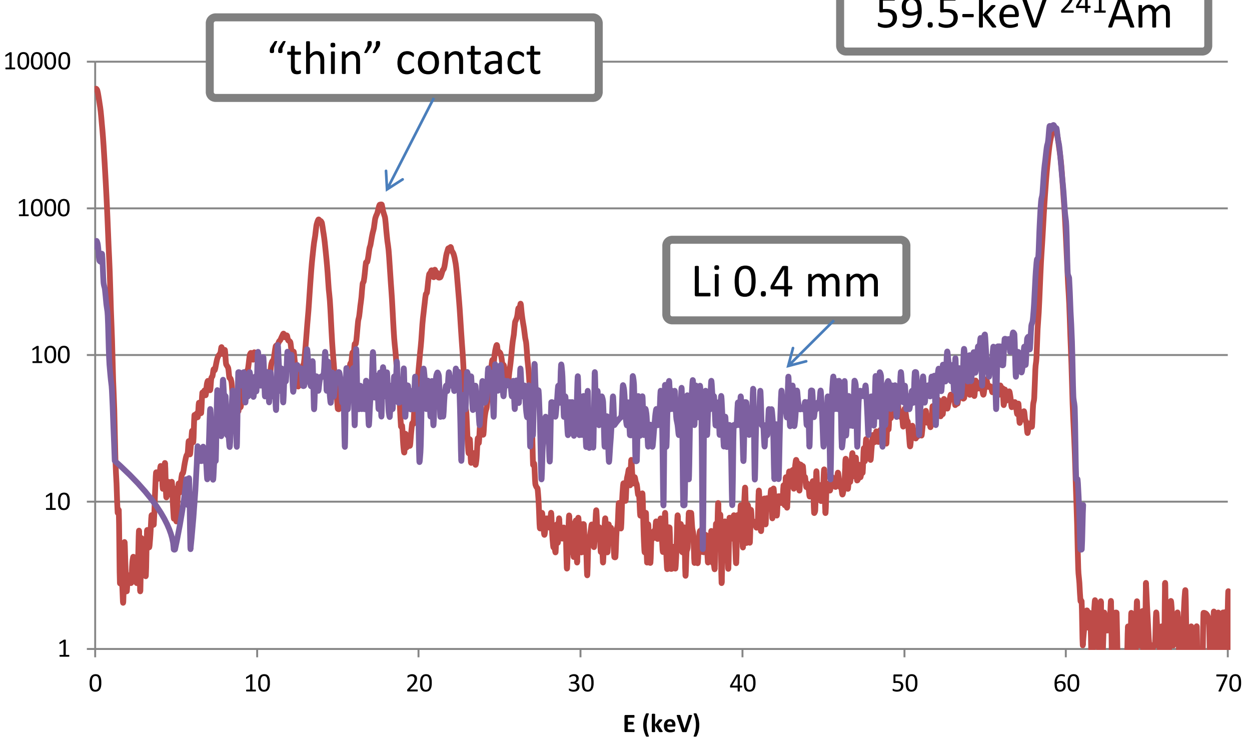
Goal: 1000kg ^{76}Ge

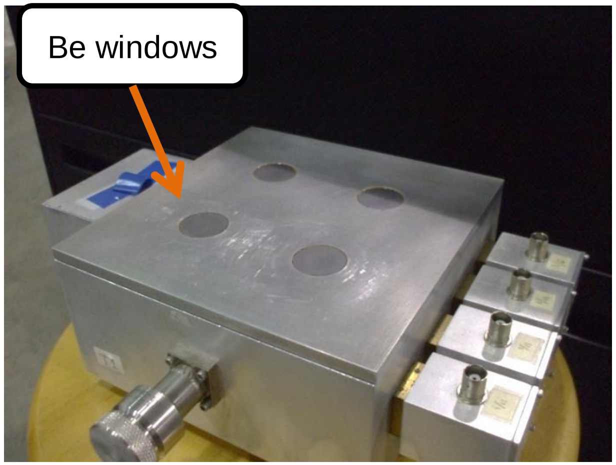
^{76}Ge \$100-\$200/g

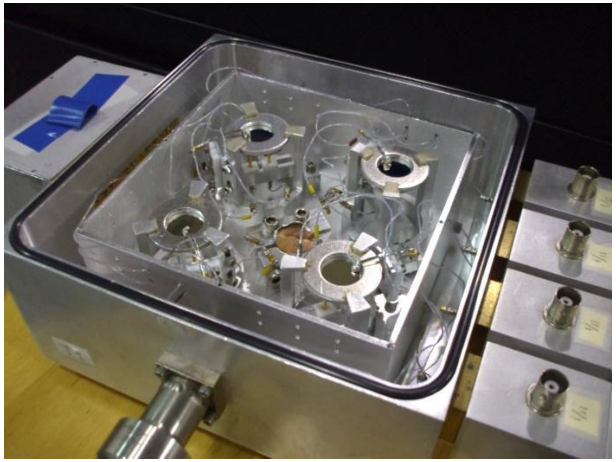
7% loss is \$7M-14M due to Li-diffused contact

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

2. Thick lithium-diffused dead layer causes spectral artifacts

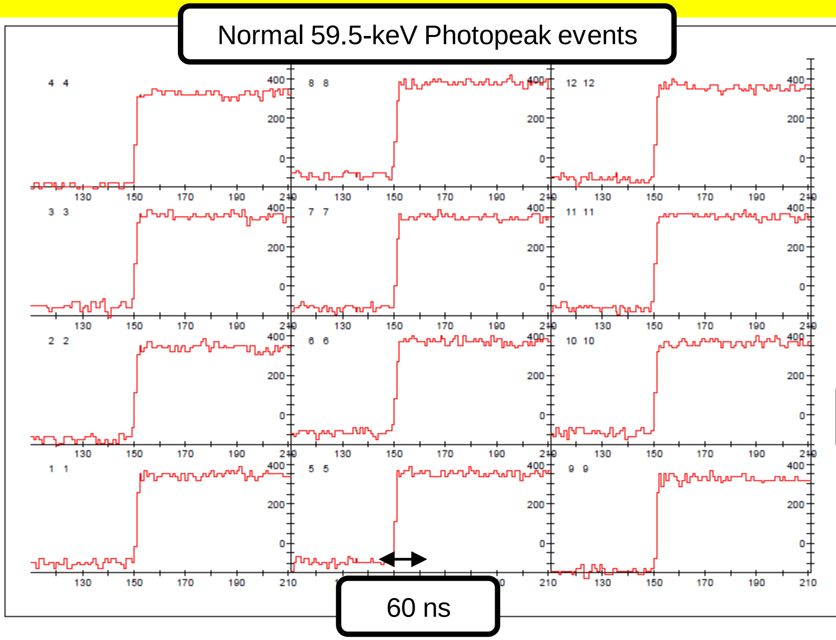


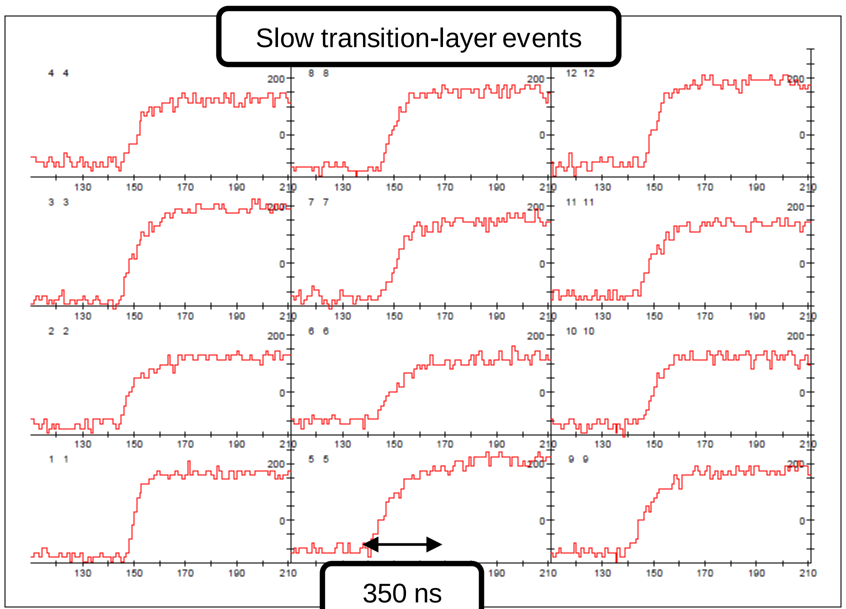


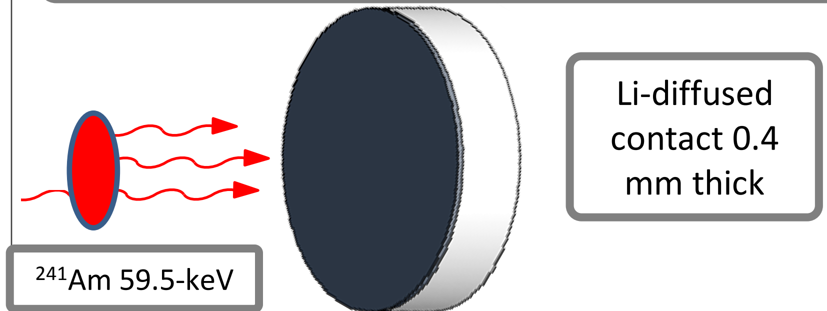


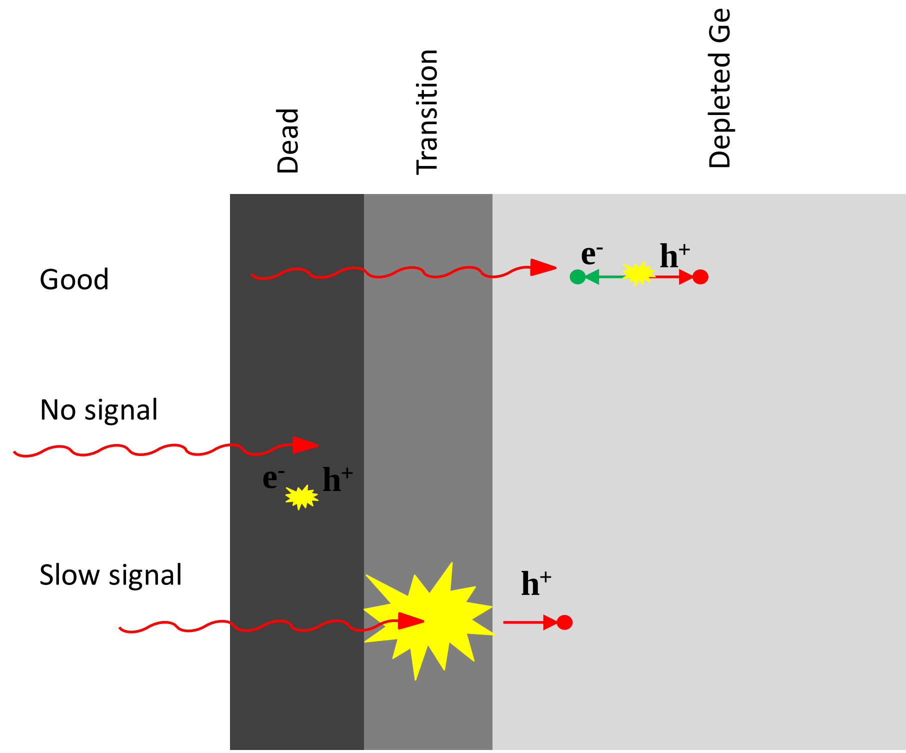
2a. Thick lithium-diffused show slow pulses from a “Transition Layer”

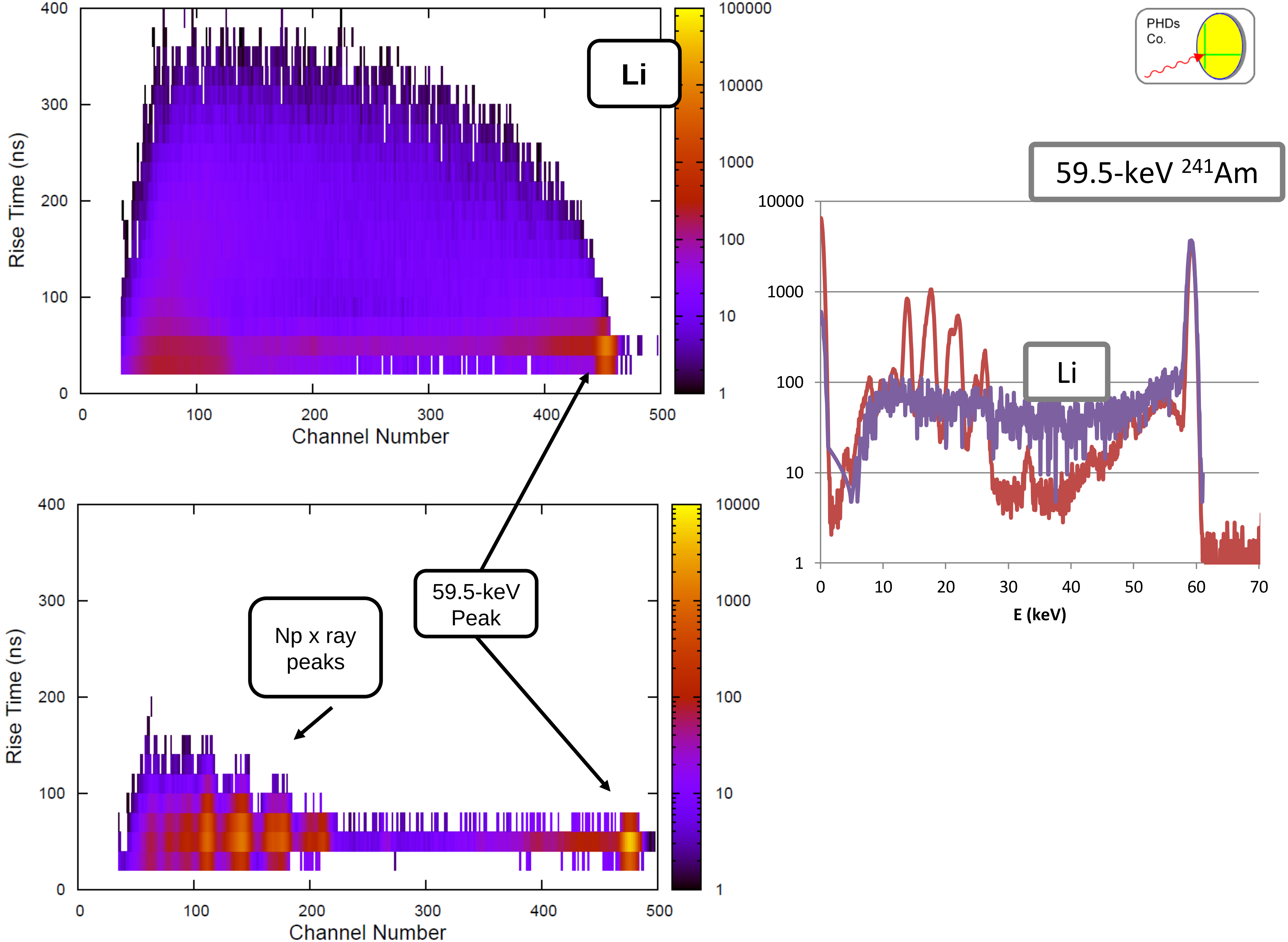
David Radford







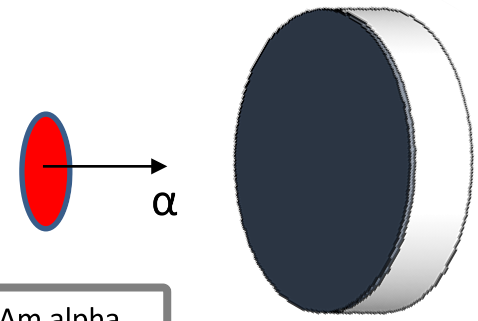




Li
Rise Time (ns)
Channel Number
PHDs Co.
59.5-keV ^{241}Am
Li
E (keV)
59.5-keV Peak
Np x ray peaks
Rise Time (ns)
Channel Number

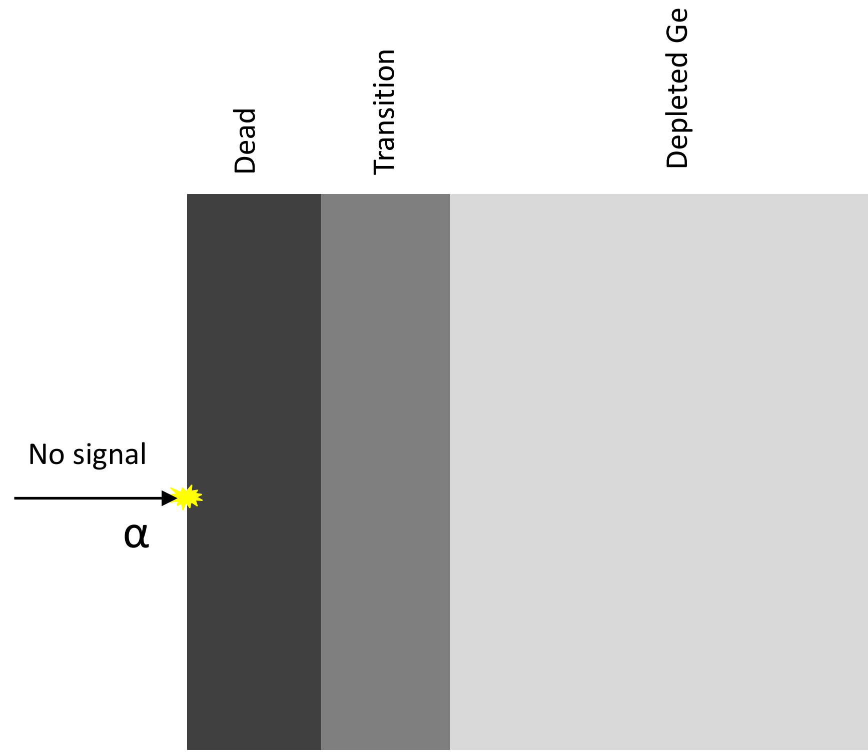
Thick Li-diffused contact has the single redeeming quality that it stops alphas (5 MeV) in 20 μm.

This has important background implications for low-level counting.



^{241}Am alpha

Li-diffused contact 0.4 mm thick



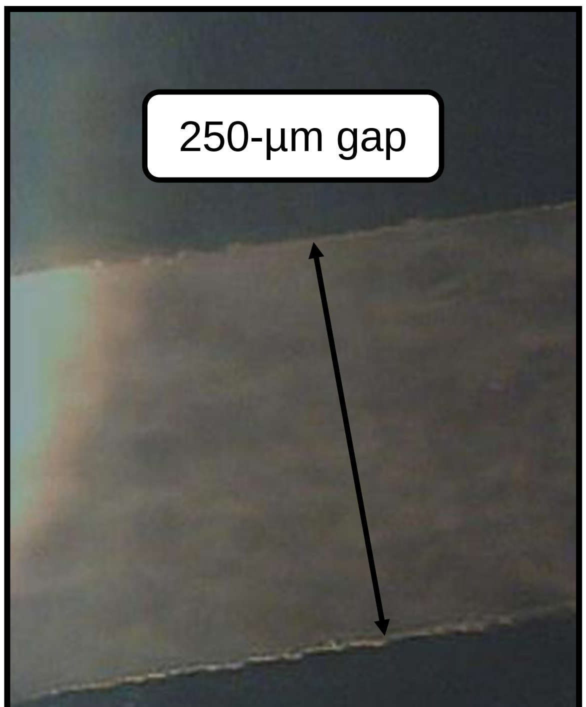
We have developed a “thin” contact technology.

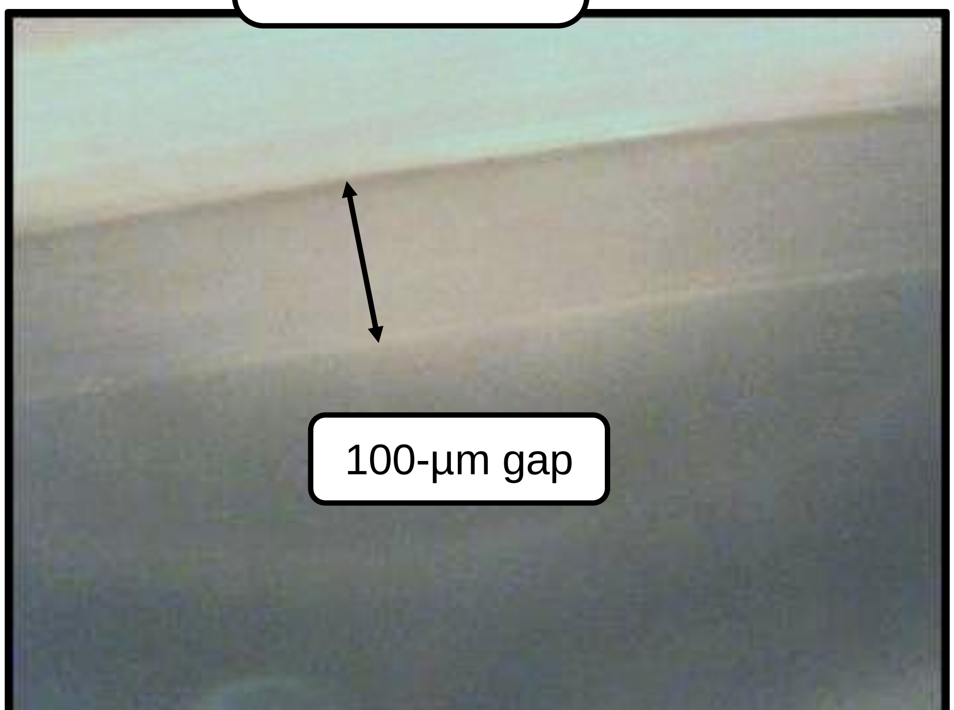
The contact has potential to:

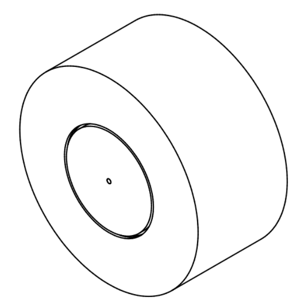
- Save valuable ^{76}Ge ($$)
- Eliminate spectral artifacts
- Eliminate slow pulses

new contact

- Forms hole-barrier!
- Good resolution
- Chemical tolerant
- Good definition
- Sputter wraps
    - ppc
- <u>Passivation viable</u>

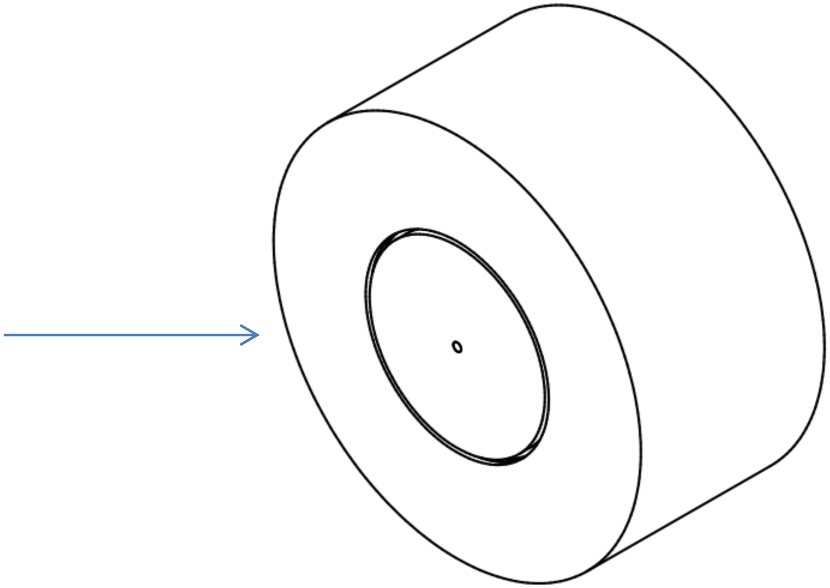


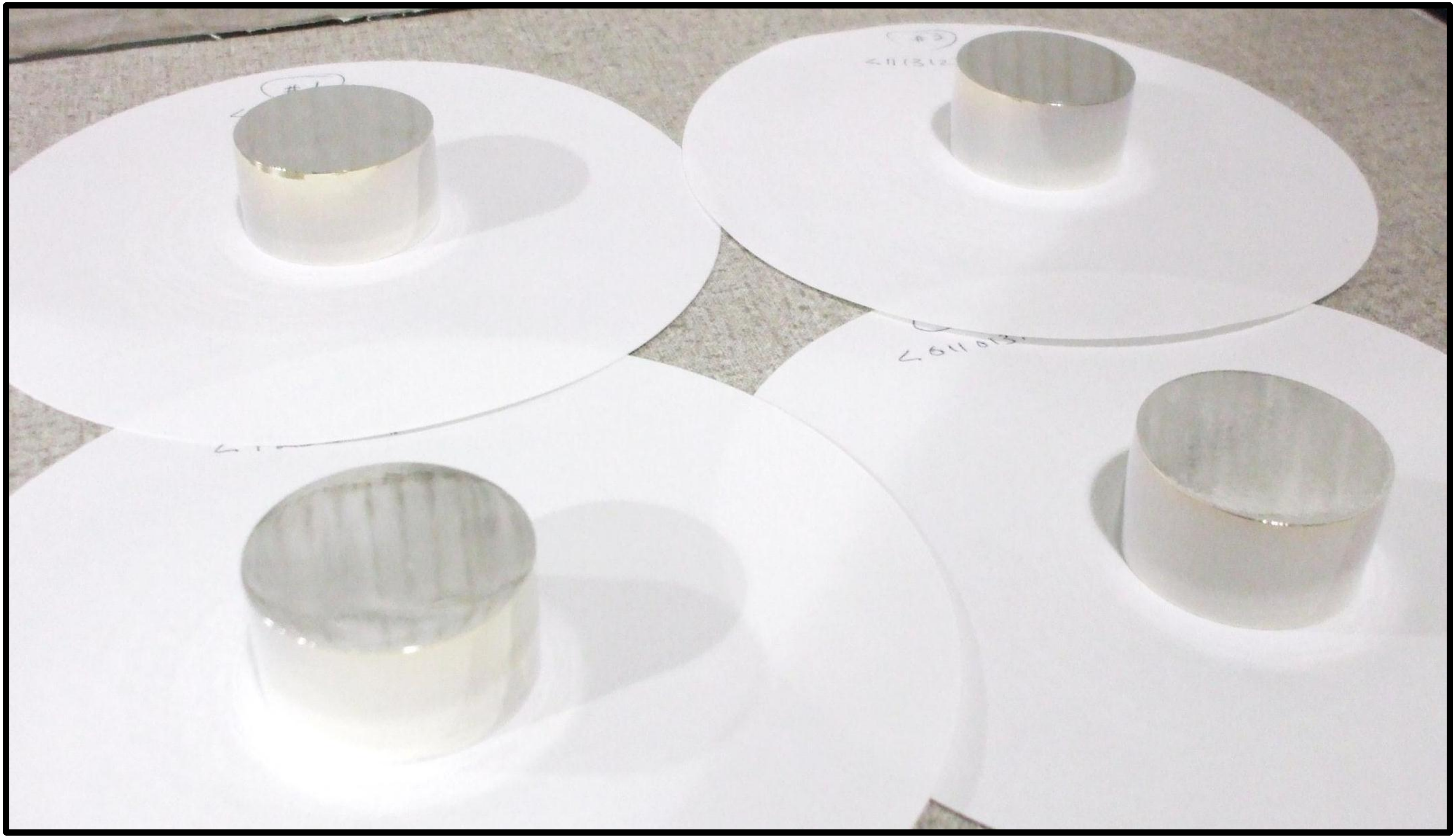




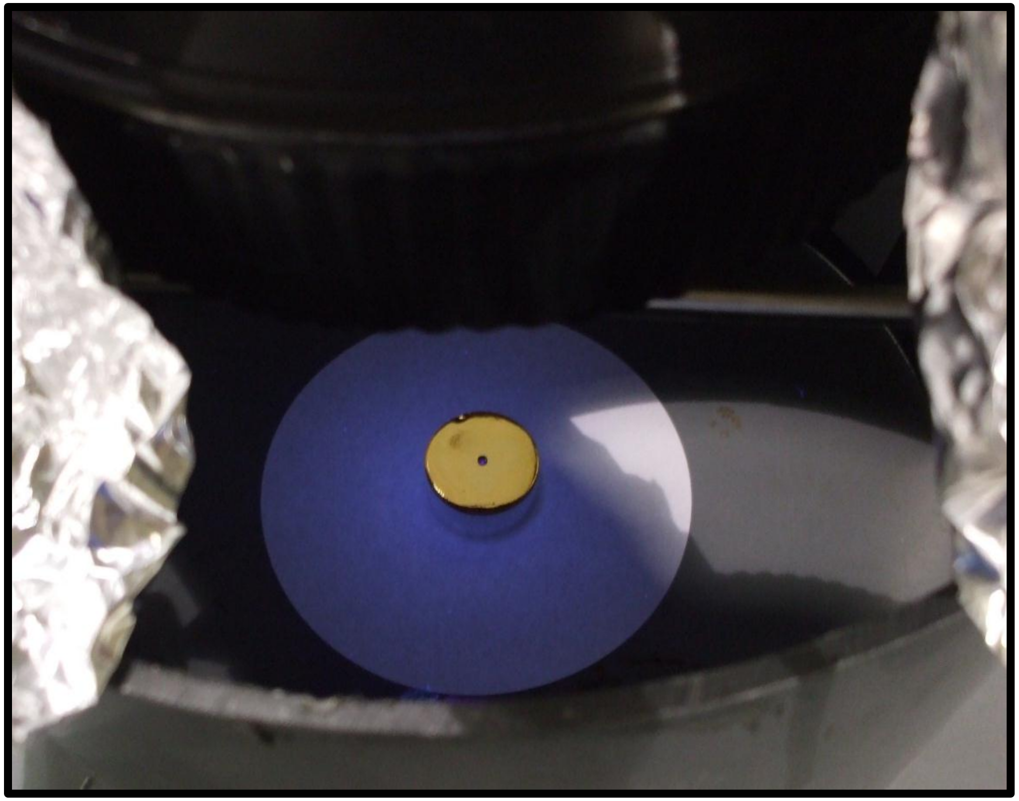
Evaluate contact

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

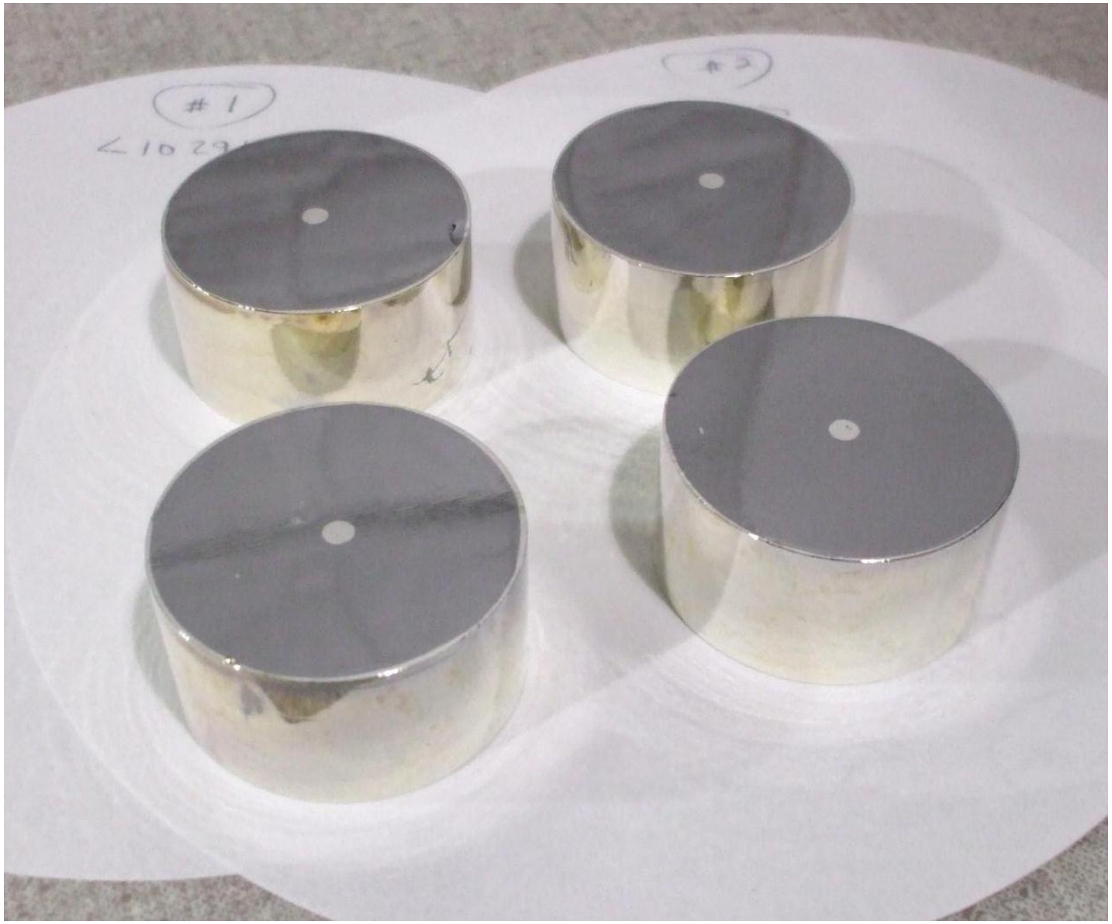




Contact before photoresist



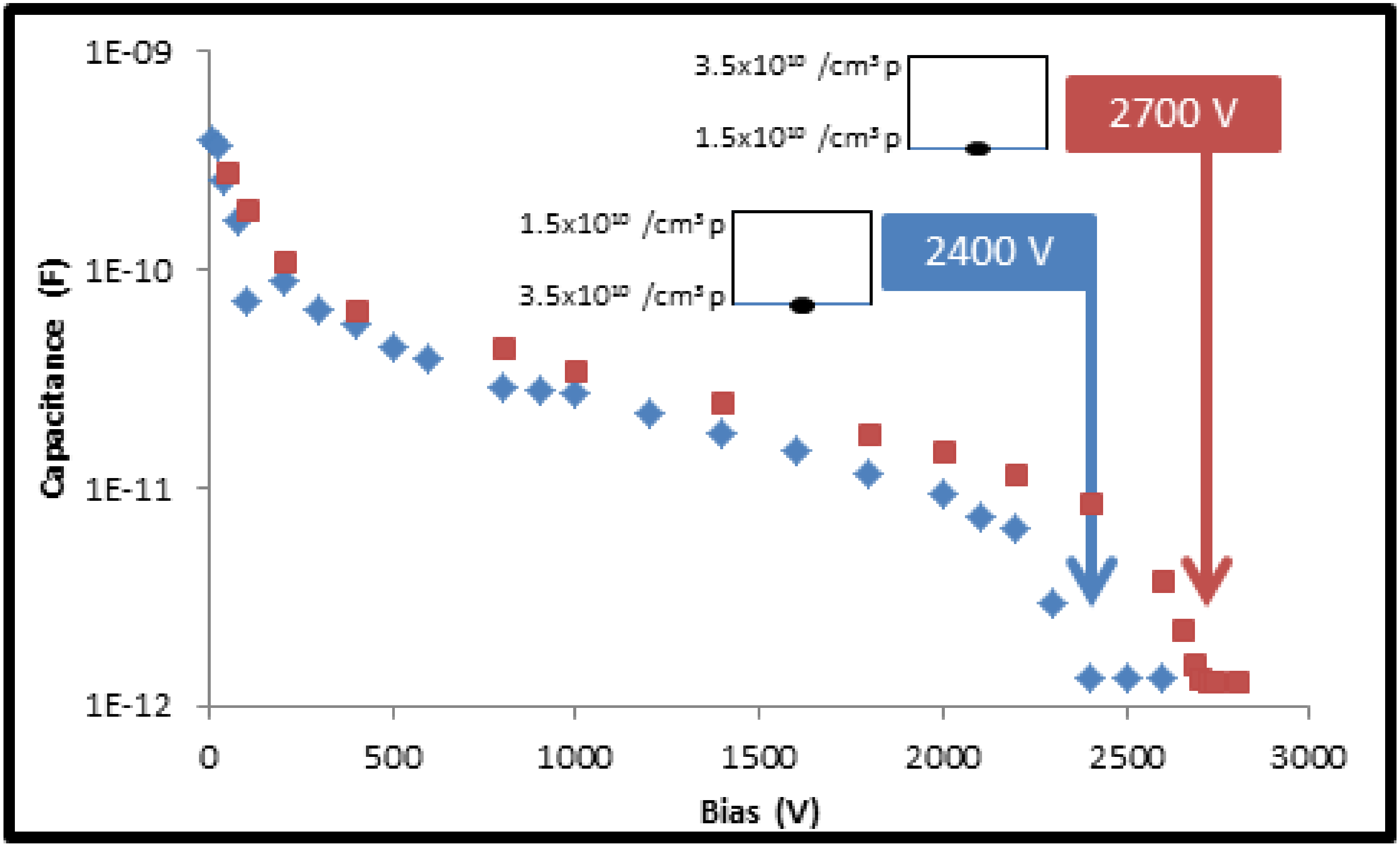
Contact with photoresist



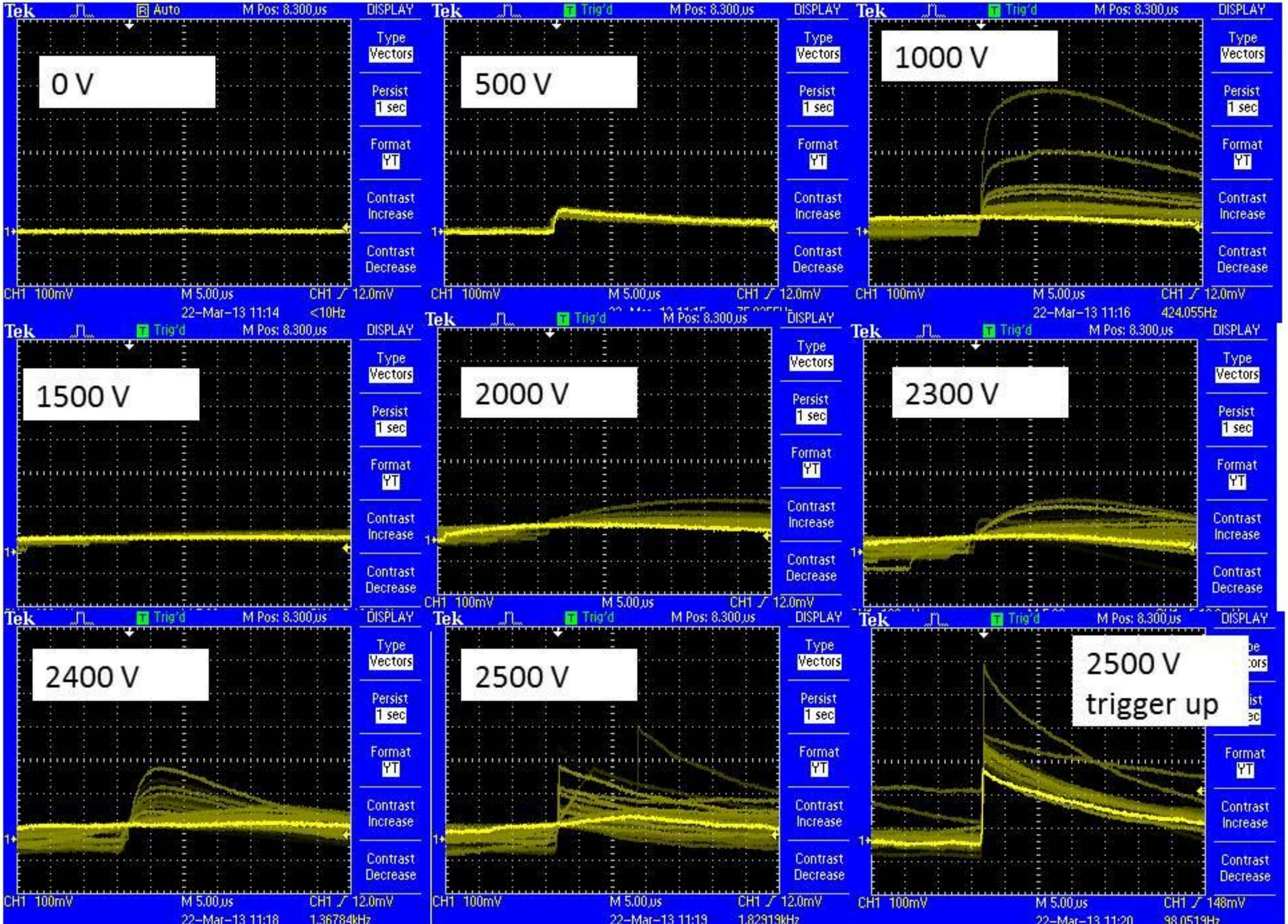
- Process refinement
- Evaluation with photons and alphas using tools shown

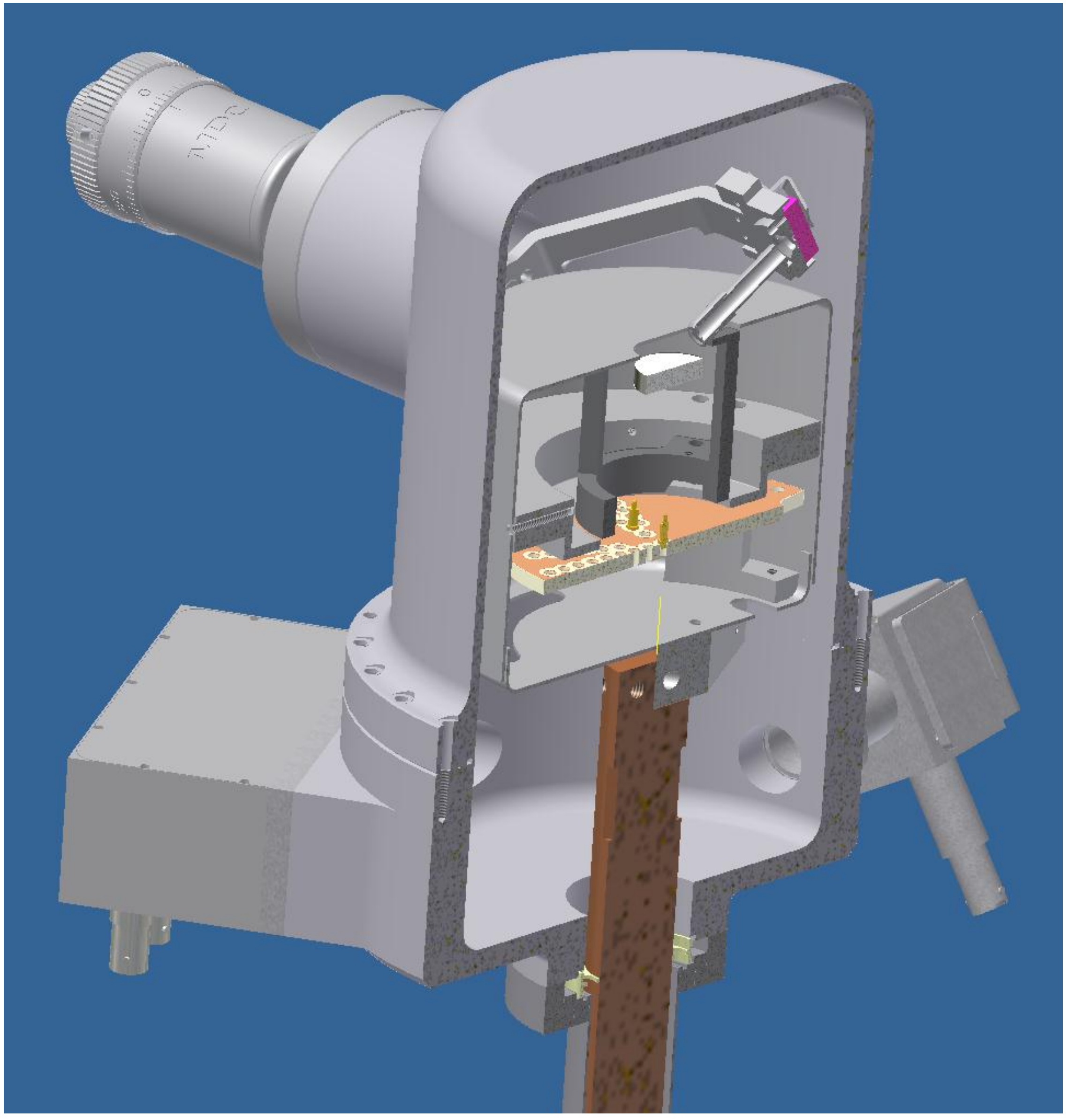
Finished ppcs
4 at a time

PHDs Co.



3.5×10^{10} /cm^3 p
1.5×10^{10} /cm^3 p
2700 V
1.5×10^{10} /cm^3 p
3.5×10^{10} /cm^3 p
2400 V
1E-09
1E-10
1E-11
1E-12
Capacitance (F)
0
500
1000
1500
2000
2500
3000
Bias (V)


0 V
500 V
1000 V
1500 V
2000 V
2300 V
2400 V
2500 V
2500 V
trigger up
Tek
Trig'd
M Pos: 8.300µs
DISPLAY
Type
Vectors
Persist
1 sec
Format
YT
Contrast
Increase
Contrast
Decrease
CH1 100mV
M 5.00µs
CH1 ∕ 12.0mV
22-Mar-13 11:14
<10Hz
22-Mar-13 11:16
424.055Hz
22-Mar-13 11:18
1.36784kHz
22-Mar-13 11:19
1.82919kHz
CH1 ∕ 148mV
22-Mar-13 11:20
98.0519Hz



Special cryostat to allow alpha-particle measurements using a variable angle of incidence, 0-60 degrees.

Segmented Rectifying and Blocking Contacts on Germanium Planar Detectors

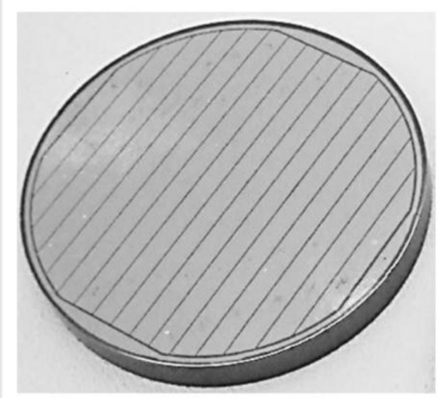
DE-SC0002477 Ethan Hull PI

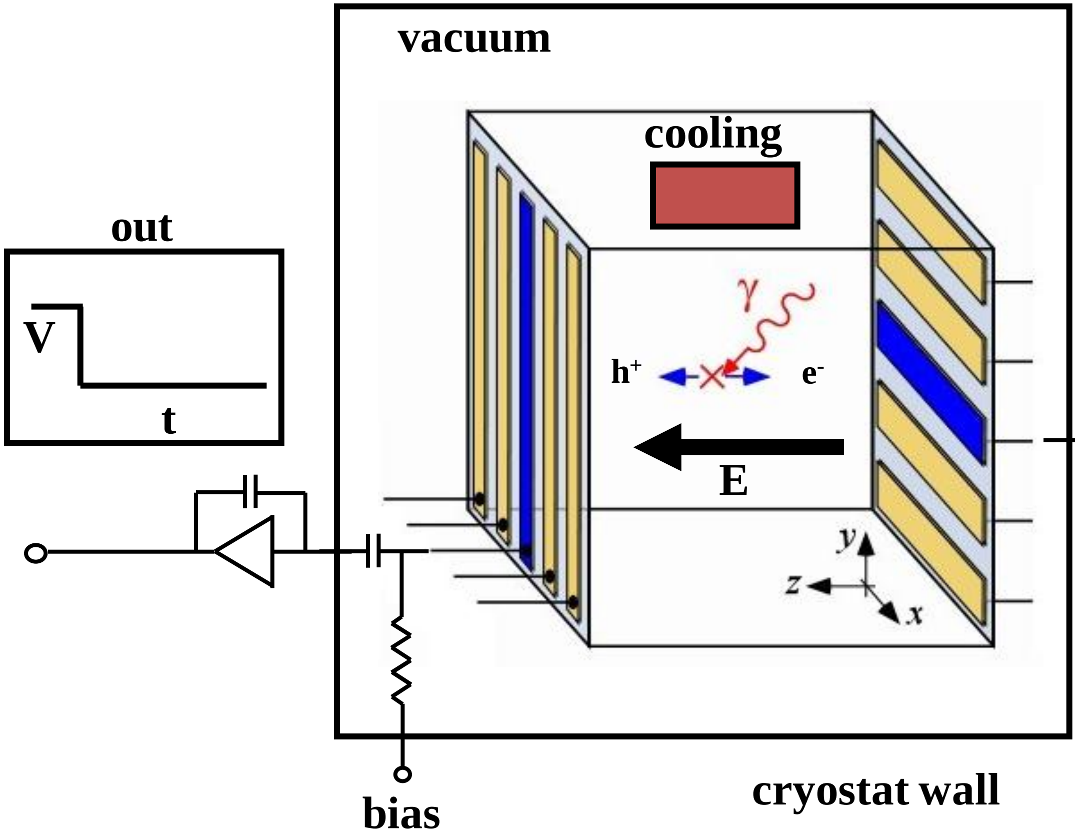
8/15/2010-8/14/2013

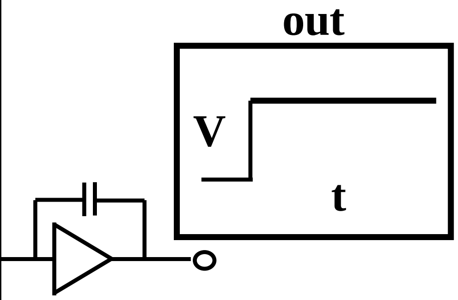
New surface contact technologies are being developed for the fabrication of segmented planar germanium detectors. Three fully functional orthogonal-strip NPX-M planar germanium detector systems with narrower gap widths have now been delivered to UMass Lowell for evaluation. The contacts have been verified to be sufficiently rugged to survive repeated thermal cycles and shipment. Measurements at UMass indicate intrinsic improvements in the detector performance as a result of the narrower gap widths. More importantly, the improved detector fabrication has been used to fabricate several commercial detectors successfully delivered to customers during the past year. More recently, the strip detector fabrication technique has been adapted to make significantly larger diameter orthogonal strip detectors.

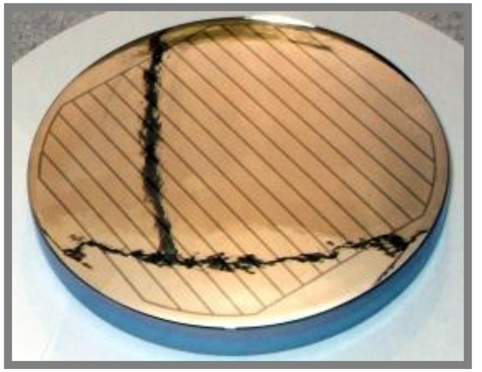
Collaboration with Kim Lister at UMass Lowell

- Rectifying *AND Segmented* contact fabrication
  - **Gaps** reduced from 500 µm to 250 µm
  - Prototypes fabricated
    - Shipped to UMass Lowell for evaluation
  - Contact fabrication transitioned into commercial detector fab
    - GeGI commercial detector systems shipped (250 µm)
  - Contacts recently extended to make larger area detectors
    - **Gaps** reduced from 250 µm to 125 µm
    - Deposition effects particular to larger area detectors









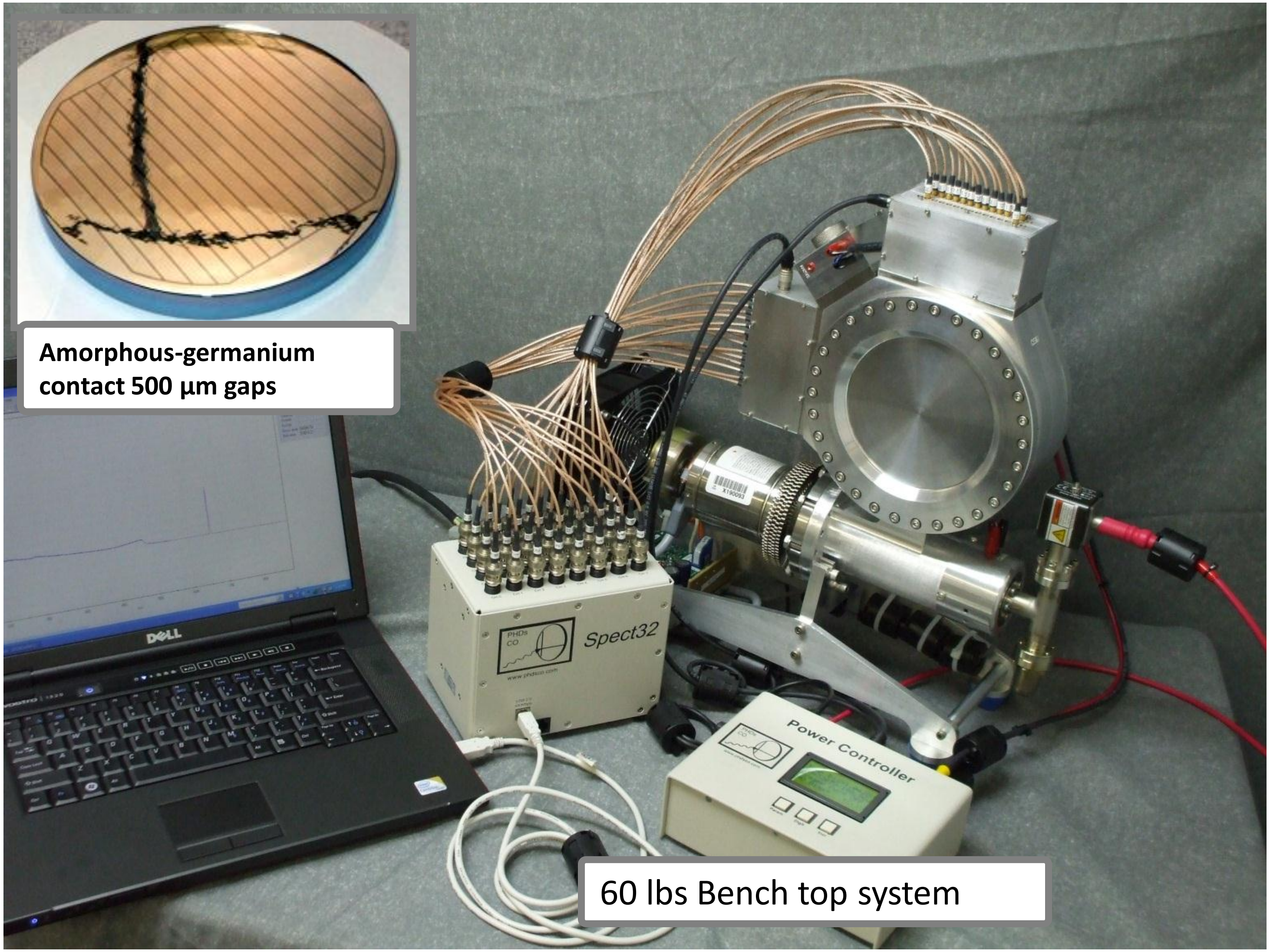
Strip detector with 0.5 mm (500 µm) gaps

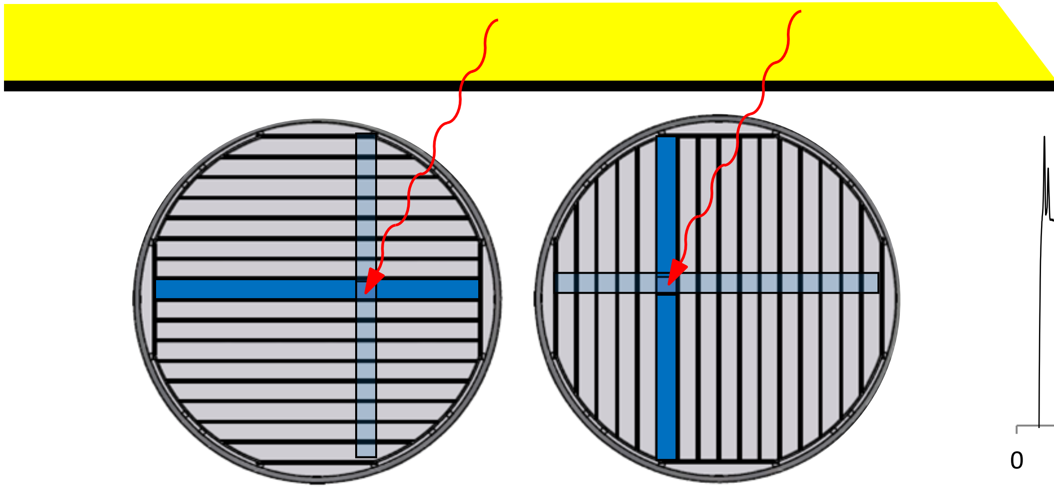
Require hole and electron barriers AND Segmentation (>1 GΩ)

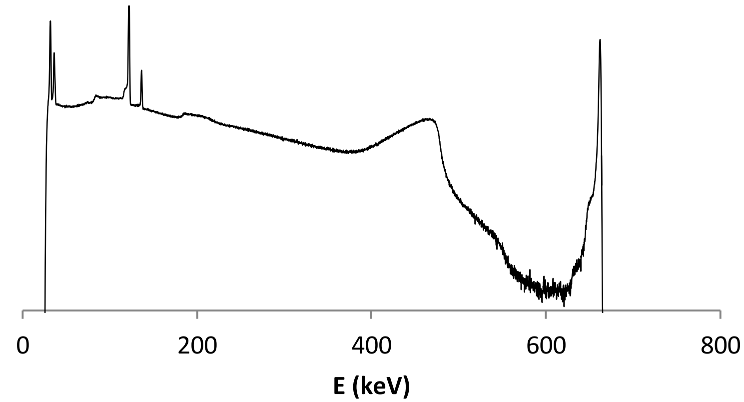
Lithium diffused contacts (~ 1 mm) are not a good option

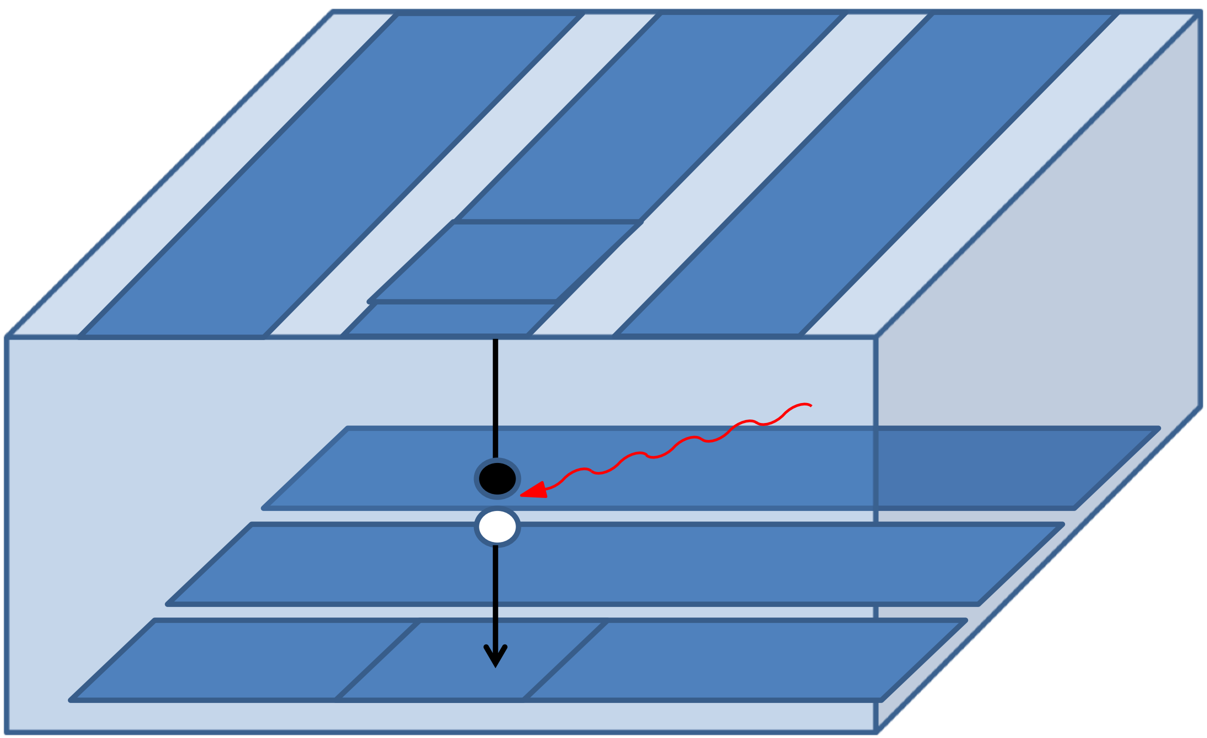
PHDs Co.

Implications of narrower gaps for strip detectors

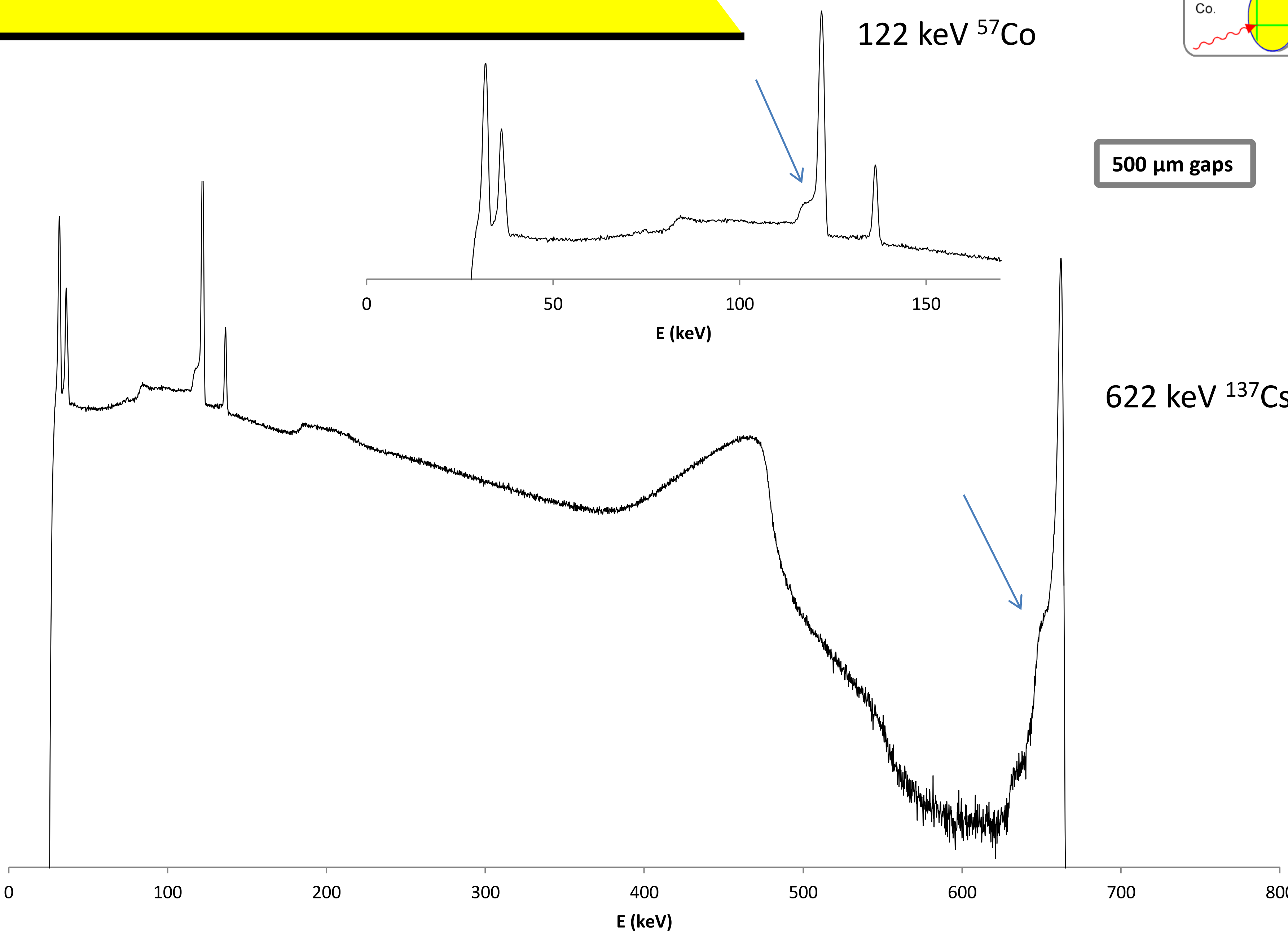






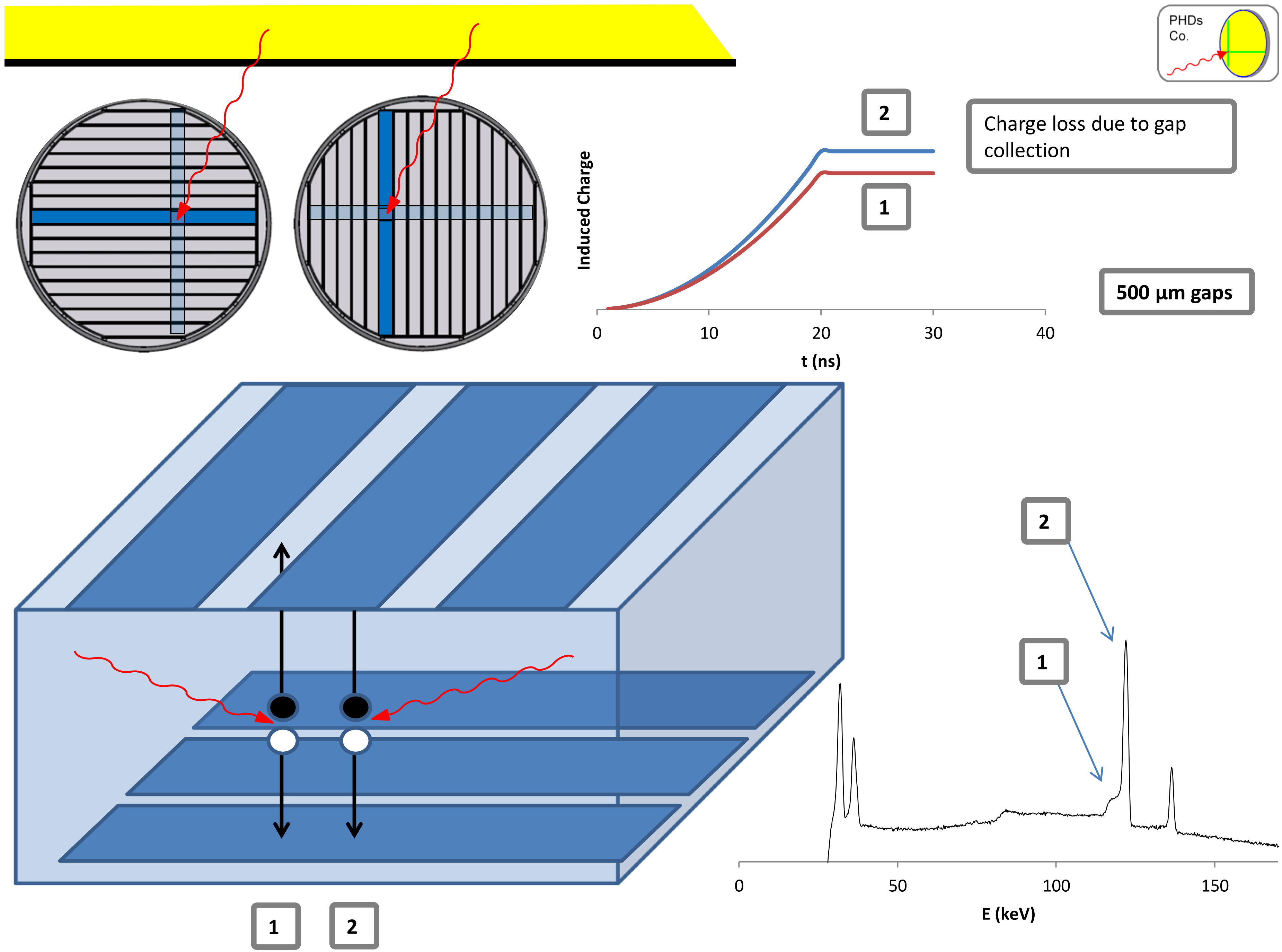


500 µm gaps



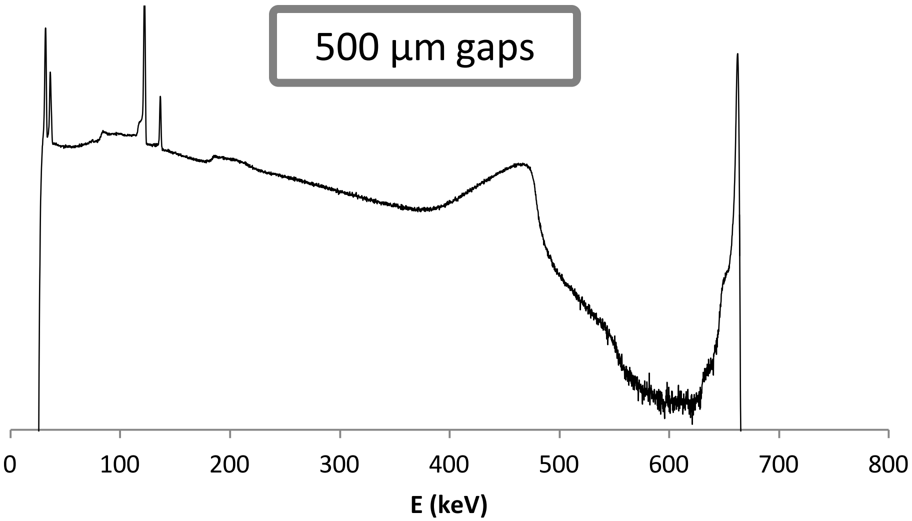
500 µm gaps

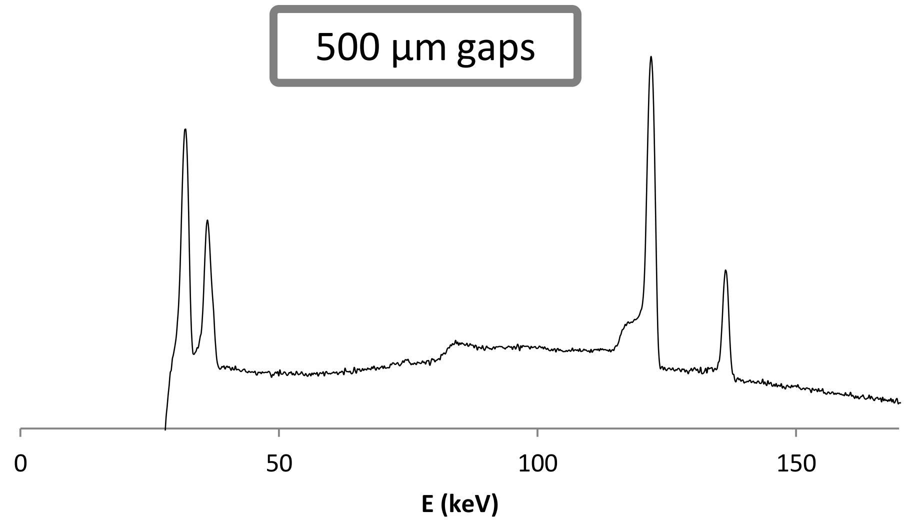
PHDs Co.

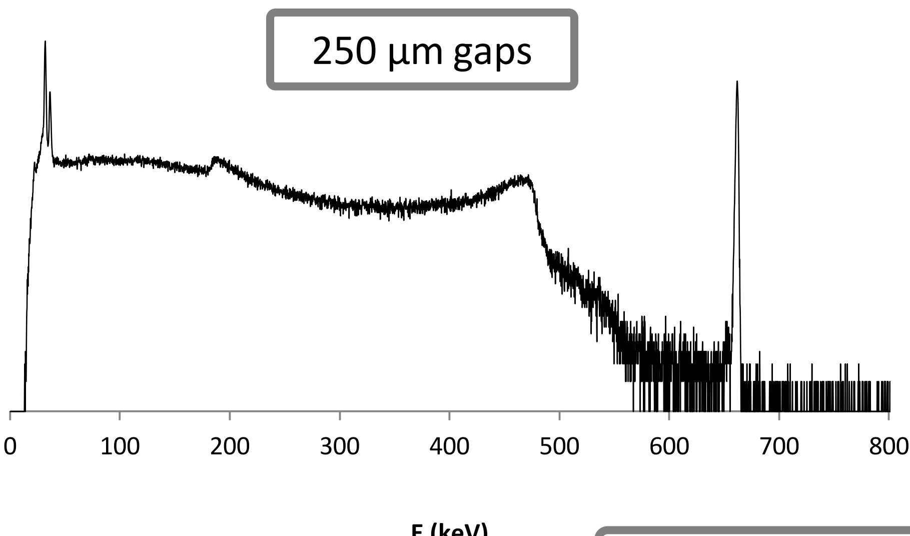


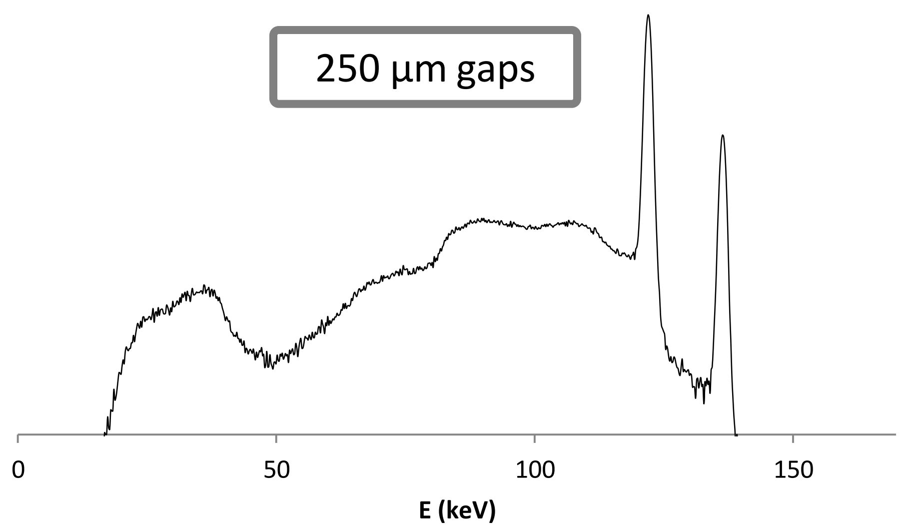
PHDs Co.
2
Charge loss due to gap collection
1
Induced Charge
500 µm gaps
0
10
20
30
40
t (ns)
2
1
0
50
100
150
E (keV)
1
2

500 µm gaps → 250 µm gaps









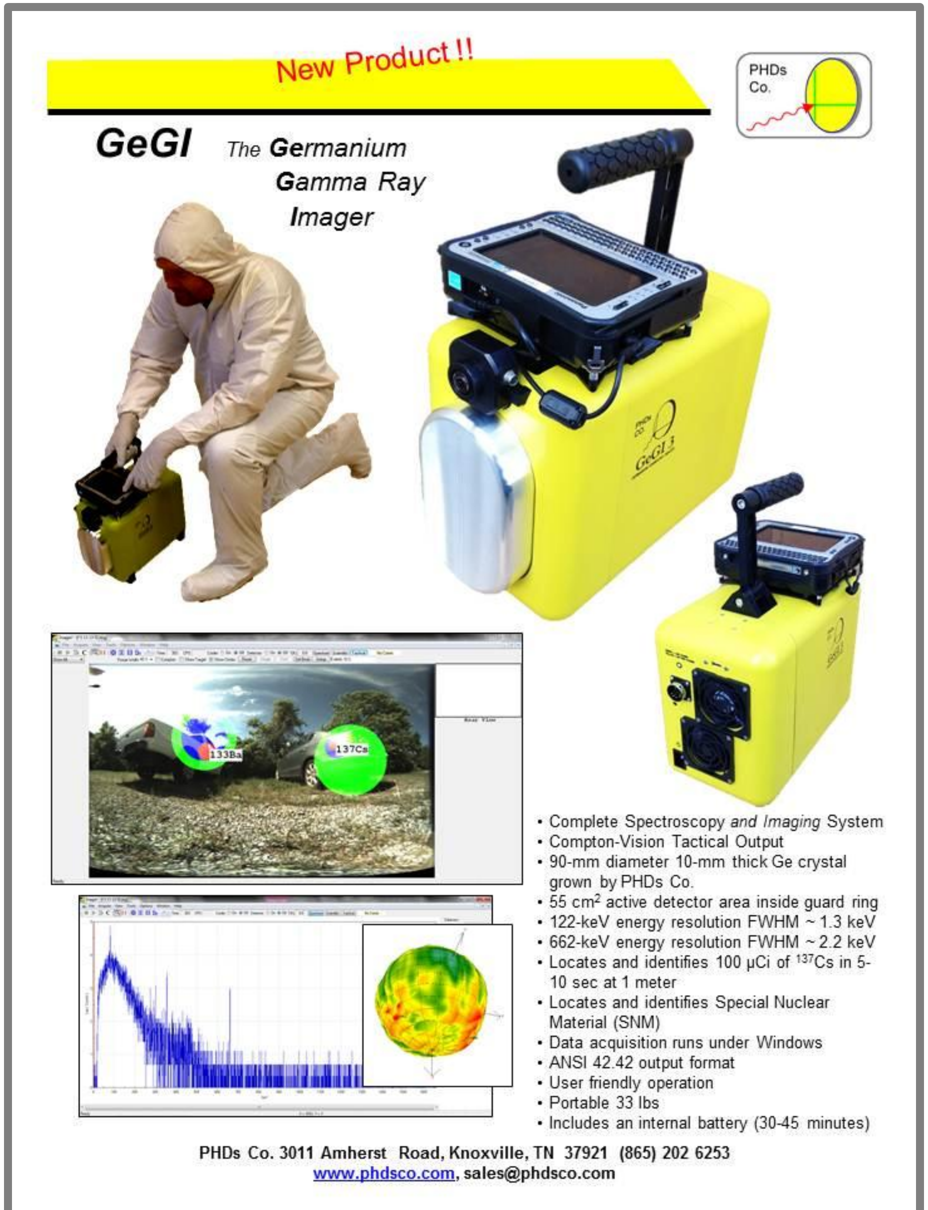
PHDs Co. results

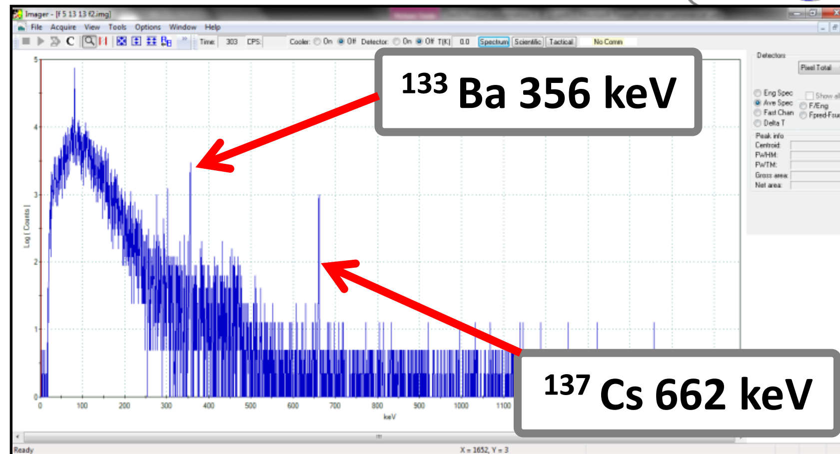
A series of 3 prototype NPX made with 250 µm gaps → UMass Lowell

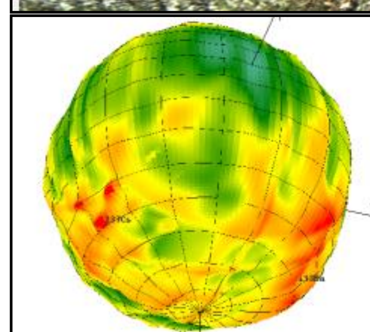
Then the 250 µm fabrication was made commercial in GeGI and GGC

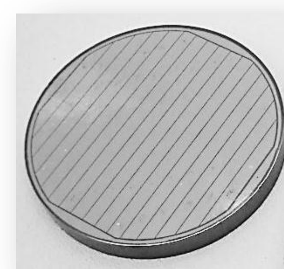
GeGI Commercial detectors use the 250 µm fabrication technology

Shipped first commercial product spring 2013





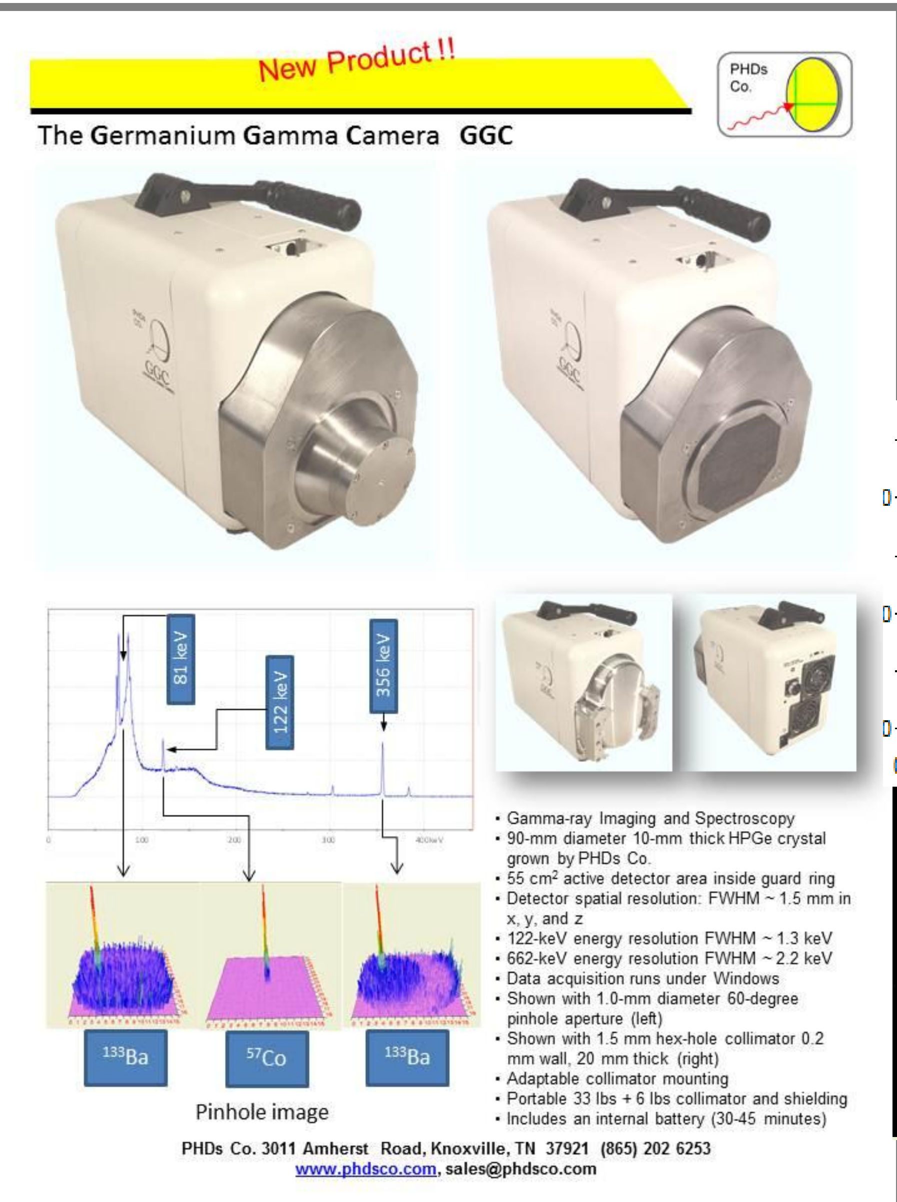


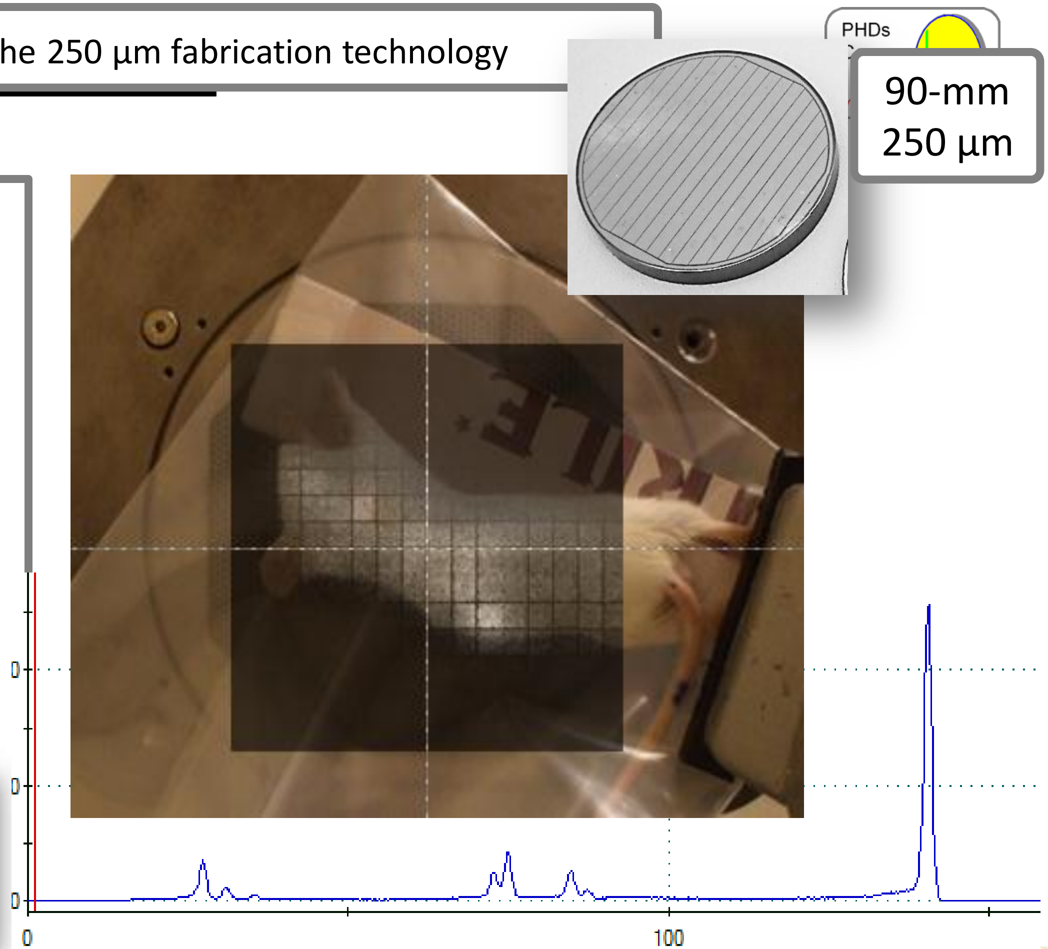


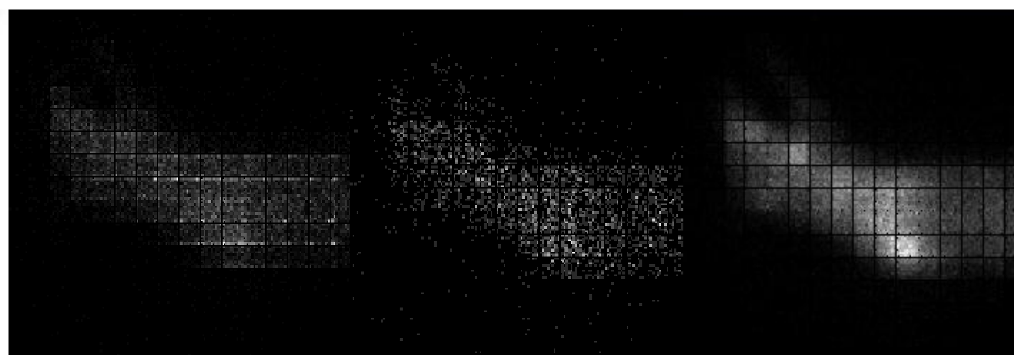
90-mm
250 µm

GGC Commercial detectors use the 250 µm fabrication technology

Shipped first prototype spring 2013

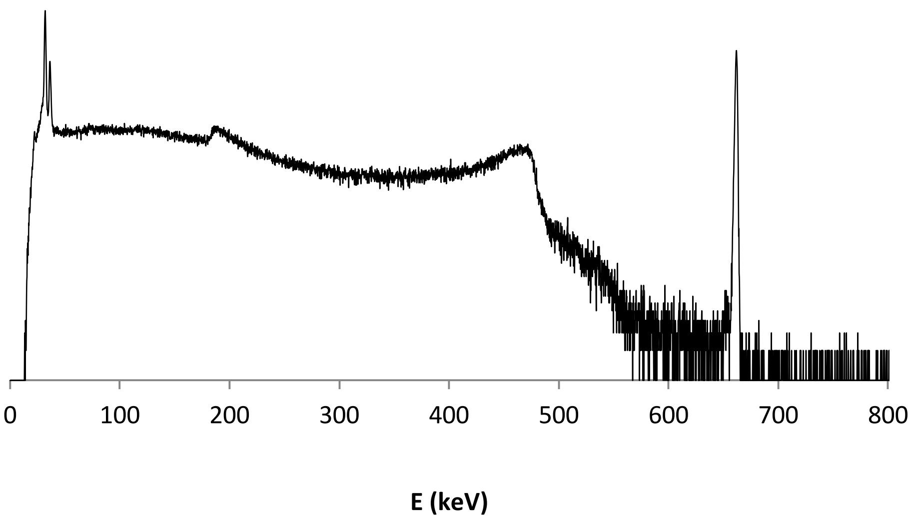


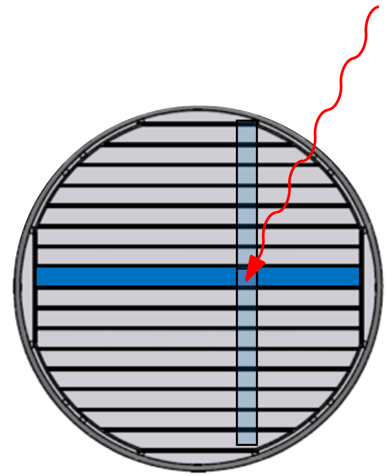




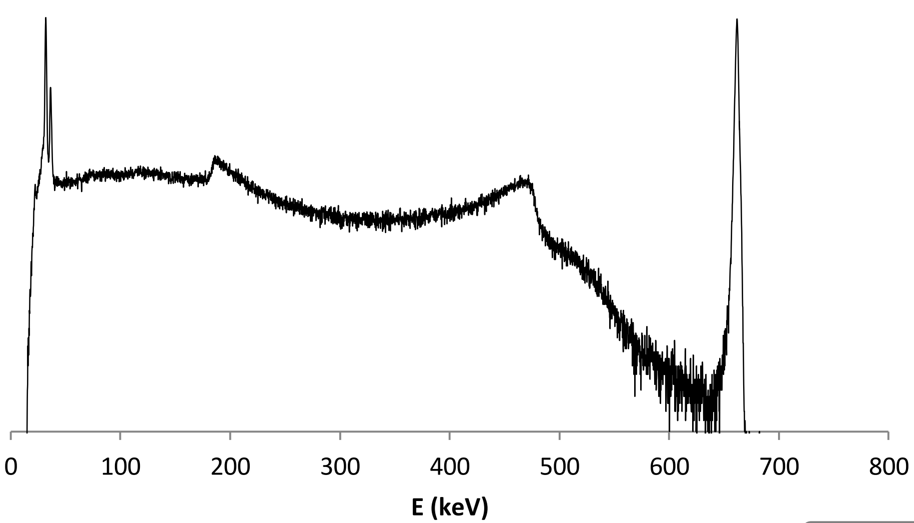
27.3 keV | 35.5 keV | 140 keV

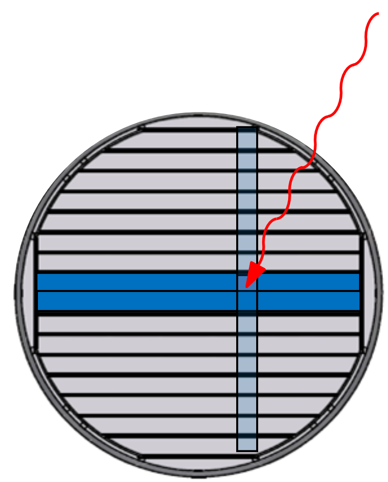
250 µm gaps





Single x and y



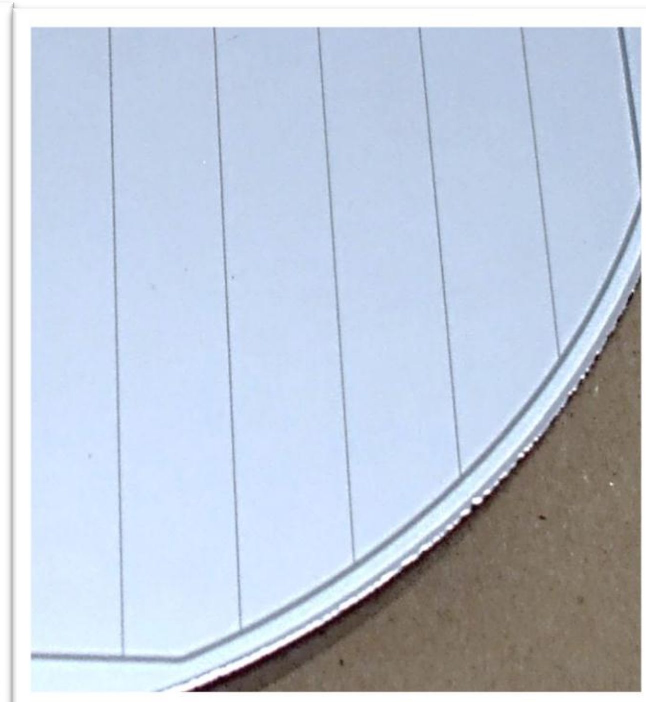


Preferentially include neighbors

There is still room for improvement in gap width

500 μm gaps
90-mm

250 μm gaps
90-mm



125 μm gaps
140-mm