

PHDs Co

777 Emory Valley Rd, Oak Ridge, TN

Established 2004

Ethan Hull, Ph.D., CEO

Richard Pehl, Ph.D., CFO

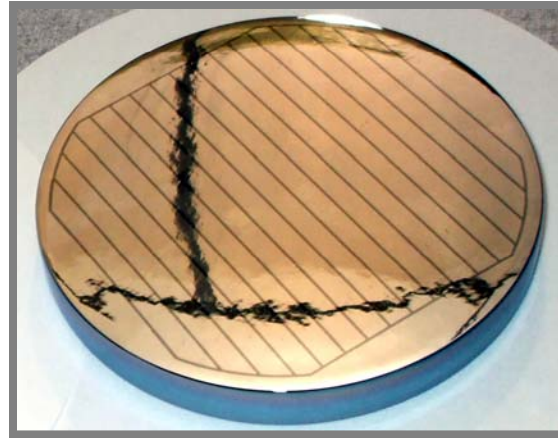
Germanium detector fabrication

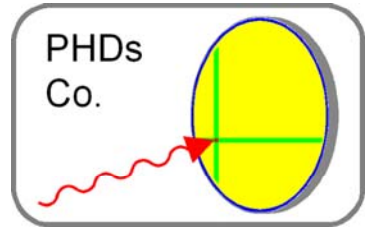
PHDs Co makes germanium semiconductor detectors

DOE Nuclear Physics

Military/Security Applications

Nuclear Medicine





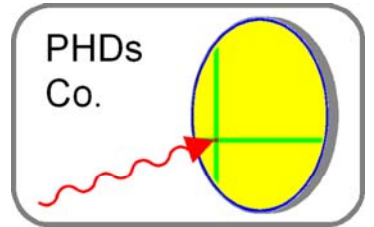
PHDs Co
Core Capabilities related to Nuclear Physics

Fabrication of Germanium Detector Systems
Detectors – Cryostats – Preamplifiers

NP Phase-II SBIR Supported Efforts Have Created Products by the end of Phase II

1. **NPX** and **NPX-M** Germanium Strip Detectors – products
Planar spatial resolution and imaging
2. **MJX** P-type point contact detectors – products
Sufficient spatial information for background reduction

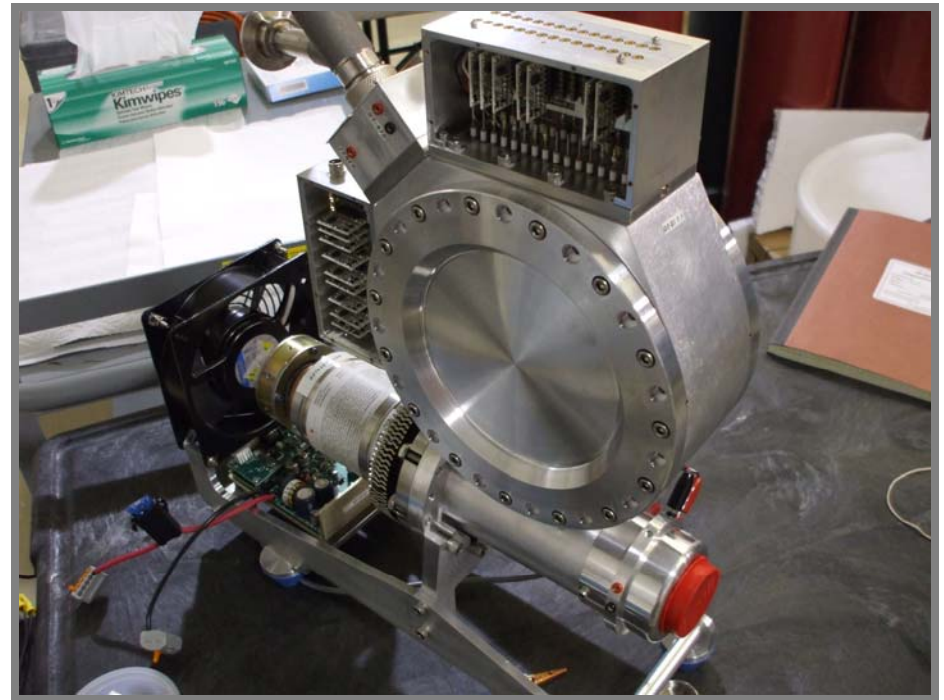
NPX and NPX-M Germanium Strip Detectors



LN₂ Cooled
NPX Systems



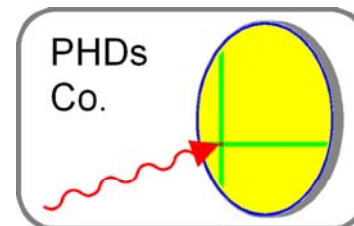
Mechanically Cooled
NPX-M Systems



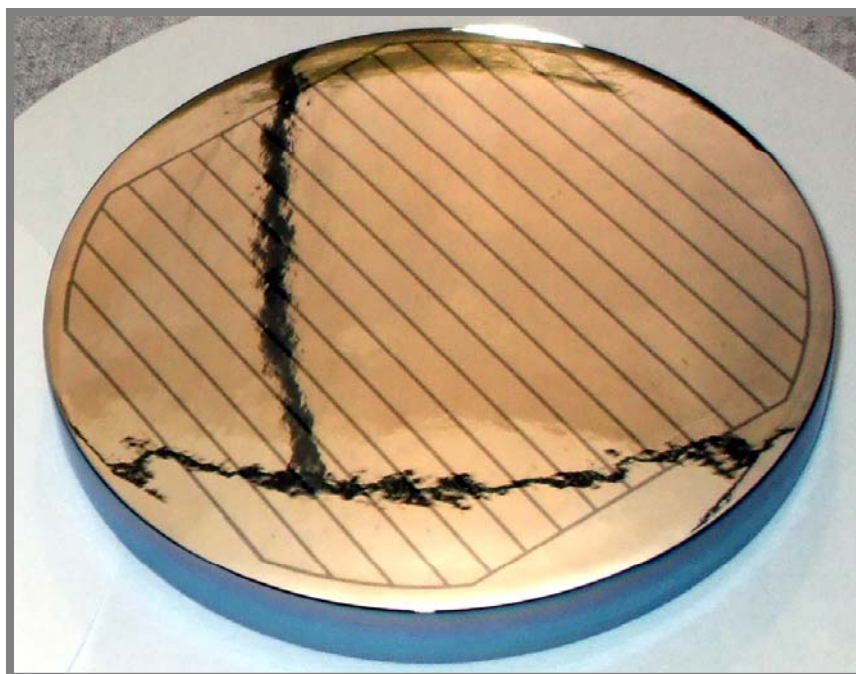
Includes Power Controller
with Bias, Preamp power,
and temperature interlocks

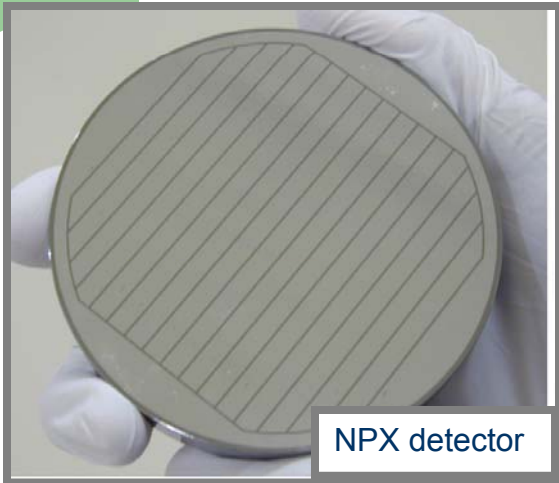
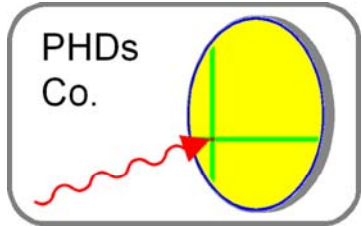


**NPX and NPX-M Germanium
Strip Detectors**



16 x 16 Strip NPX Detector





NPX detector

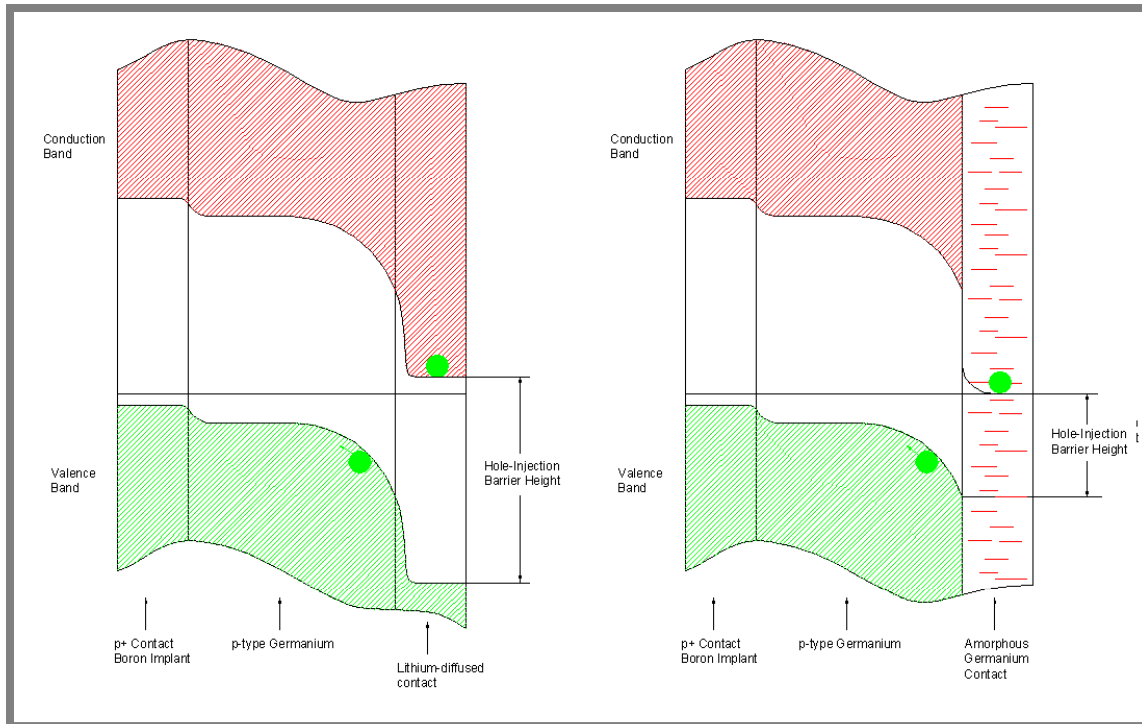
Germanium Semiconductor Detector technology

The strips of the detector must:

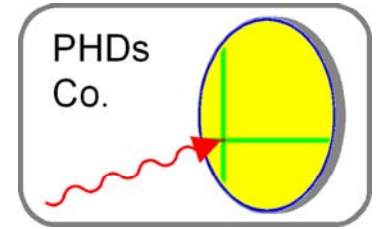
Rectify and block (form barriers) to withstand ~ 2000 V/cm

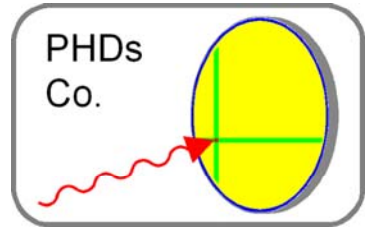
Electronically segment when biased ~ 100 G Ω

Conduct Sufficiently to prevent excessive series noise

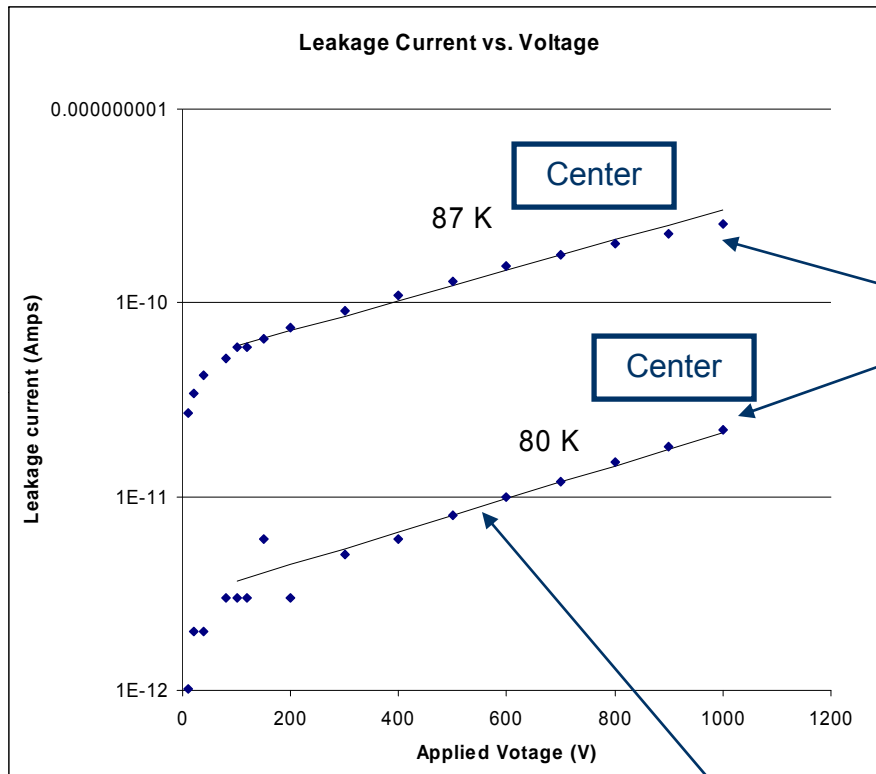


**Sample test detectors
are used to tune
fabrication recipe**





Barrier Height! Most Important factor.



T – dependence $j \sim \exp(-\phi/k_B T)$

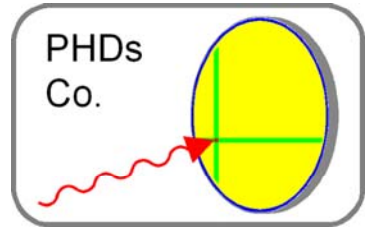
Contacts take high electric field without breakdown

Barrier Height $\phi = .30$ eV, not high enough! Too temperature sensitive.

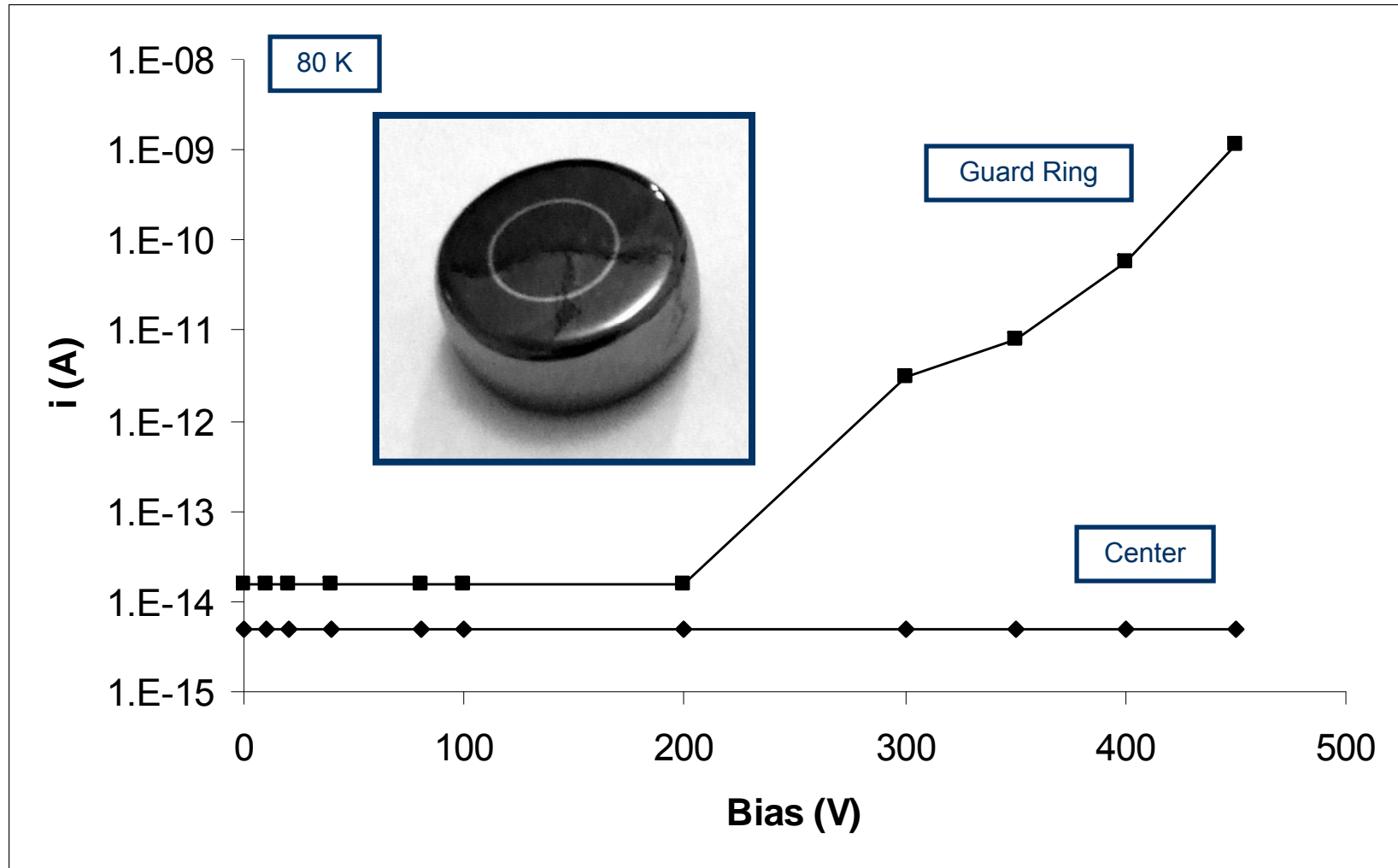
Density of states $N_f \sim 5 \times 10^{17}$ 1/eVcm³

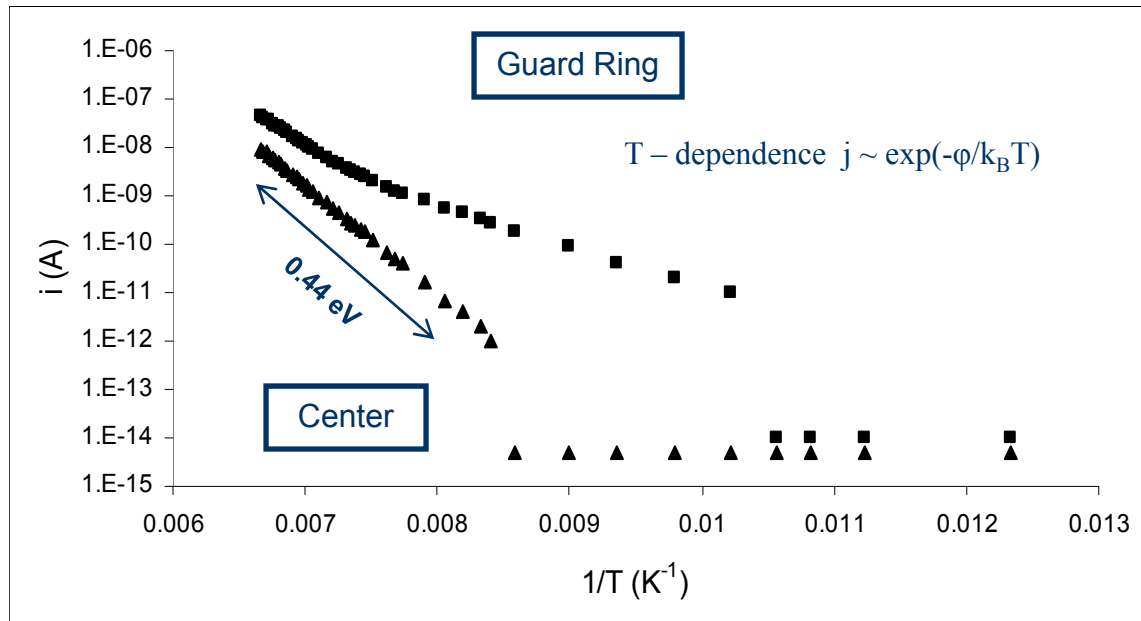
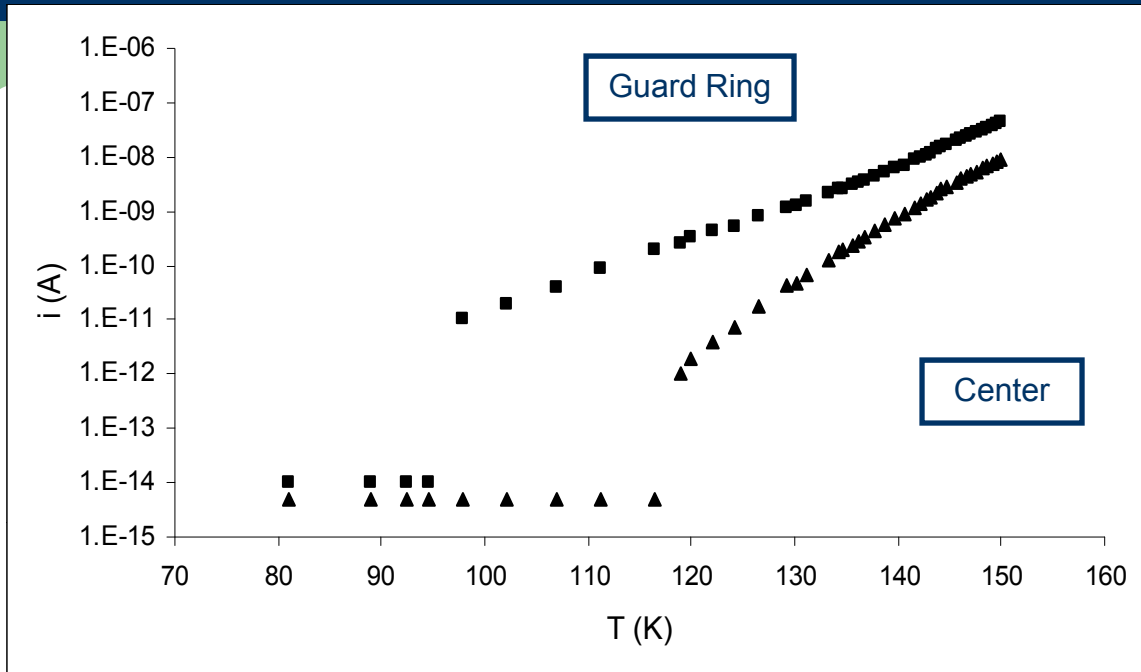
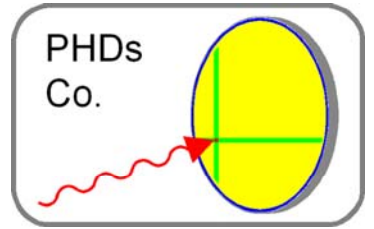
$$j = j_{\infty} \exp(-\{\phi - [(\epsilon_0 \epsilon_{Ge} / N_f)^{1/2} (V + V_{depl}) / d]\} / k_B T)$$

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.



Higher barrier height results in lower leakage current – in this case it is not measurable at 80 K!

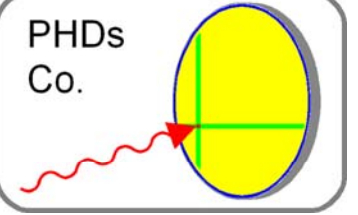




Barrier Height $\phi = 0.44$ eV
eliminates temperature
sensitivity below ~ 120 K!!

NPX-M Germanium Strip Detectors

PHDs
Co.



Continued Detector System development

Vacuum cryostat

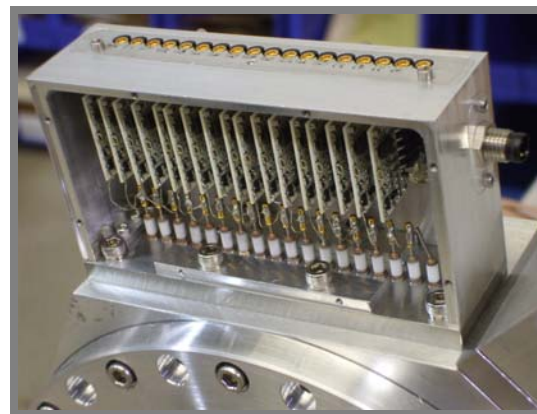
- Mechanical cooler
- Vacuum design and maintenance

Preamplifiers

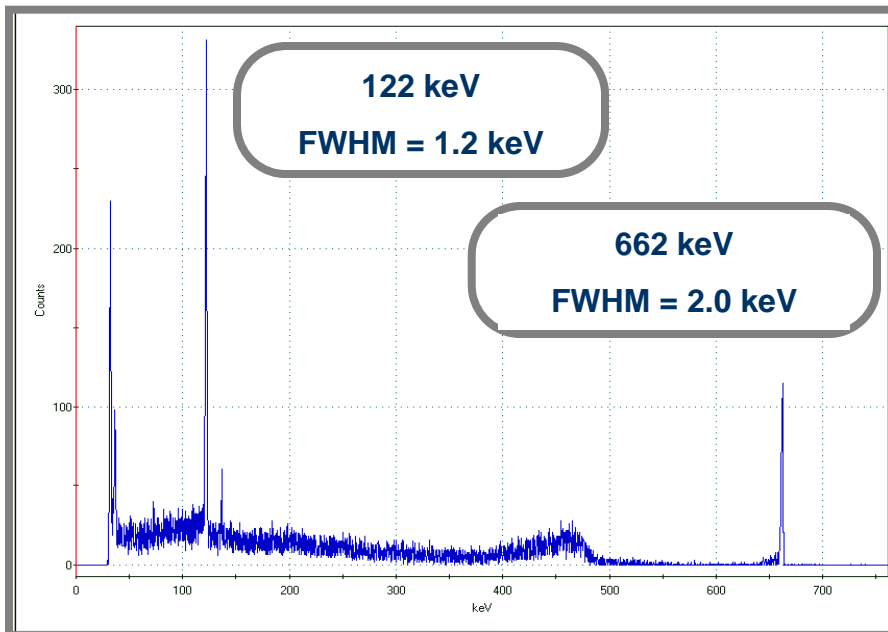
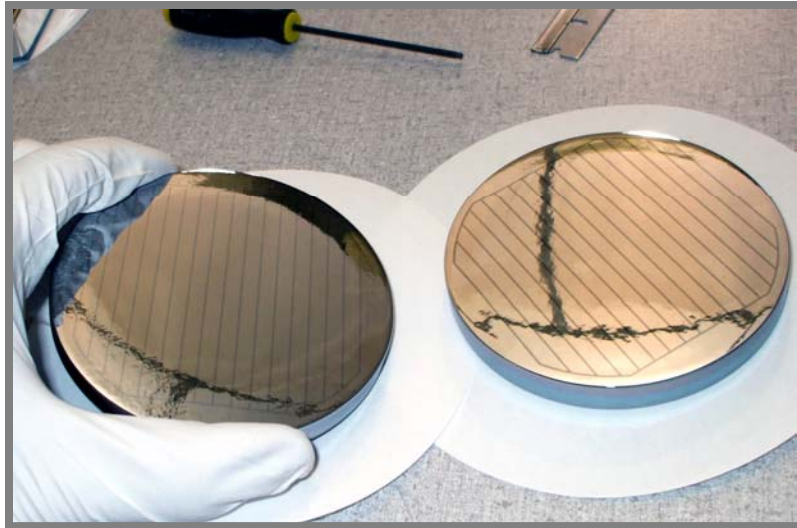
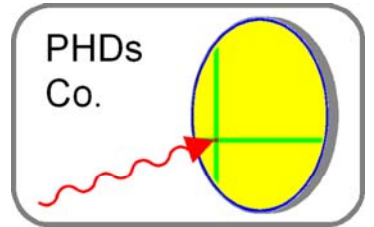
- Minimize “cross-talk”
- Eliminate instabilities (oscillations)
- Eliminate ringing
- Minimize noise

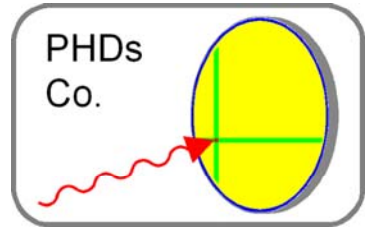
Power control system

- Reliable system control and temperature interlocking to safeguard the detector



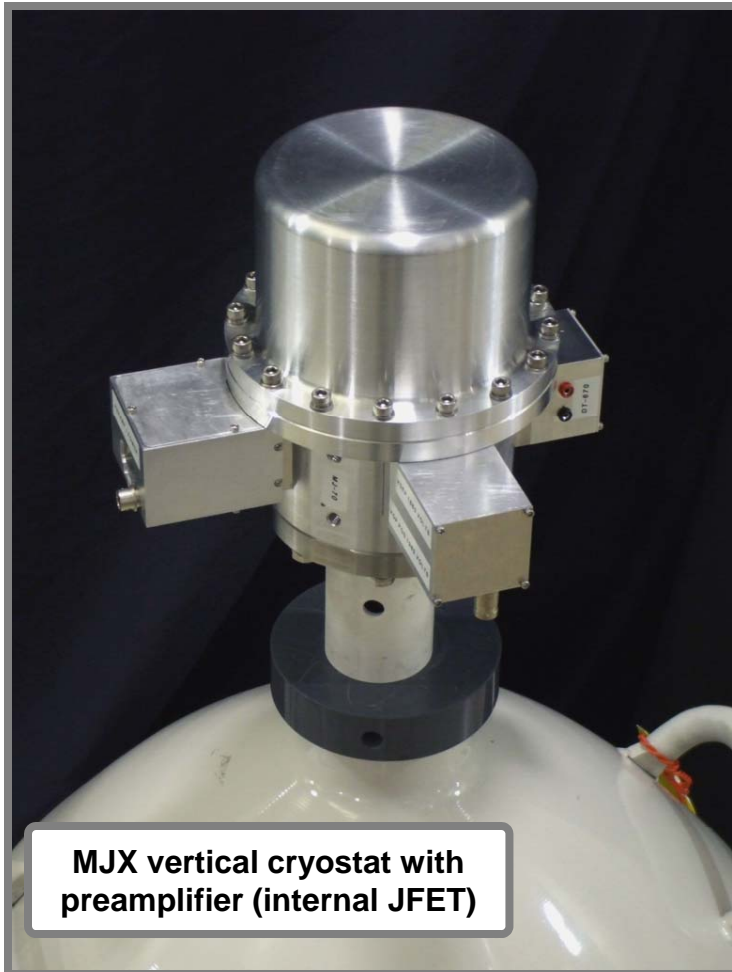
NPX-M Germanium Strip Detectors





MJX Germanium Detectors

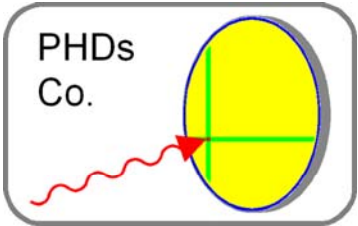
LN₂ Cooled **MJX** Systems



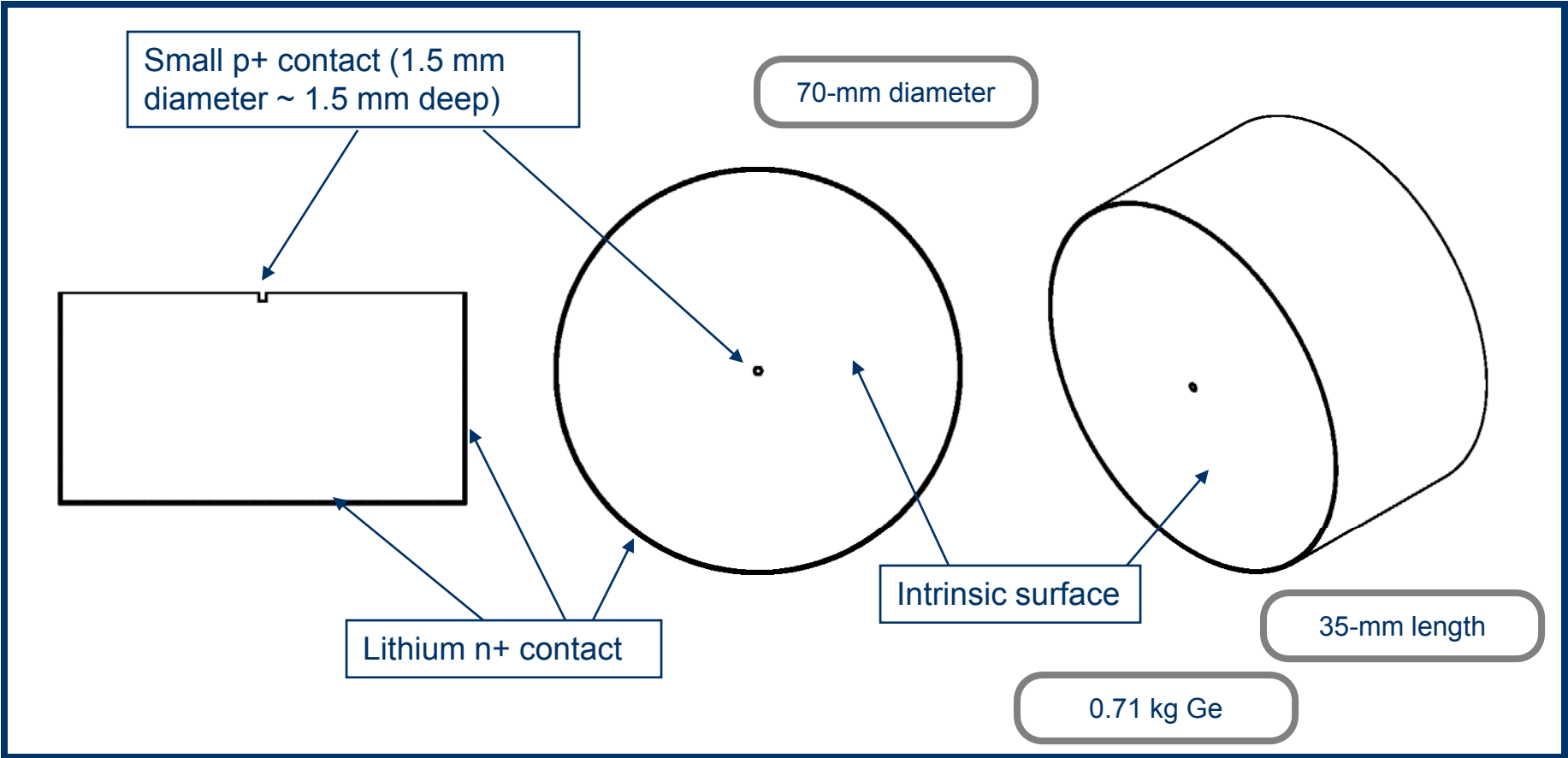
MJX vertical cryostat with preamplifier (internal JFET)

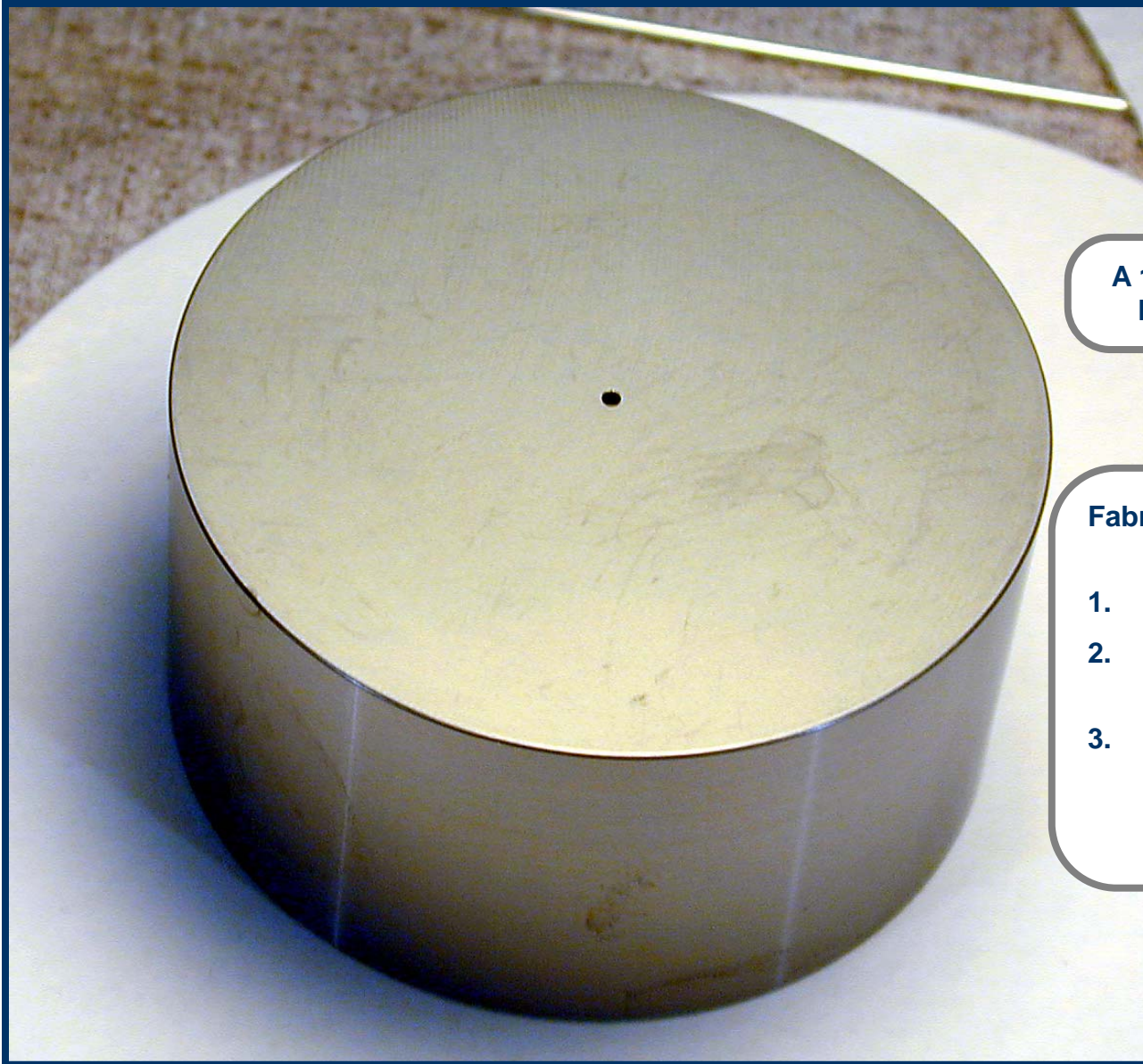
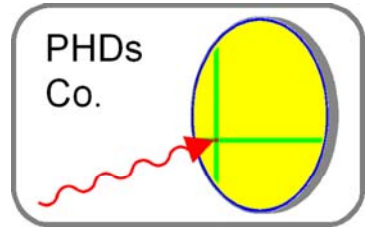
MJX Detectors are optimized for low-background counting applications like Majorana

Highly experimental detector designs – **including detector designs created by the Majorana collaboration**



MJ70 p-type point contact detector -- LANL



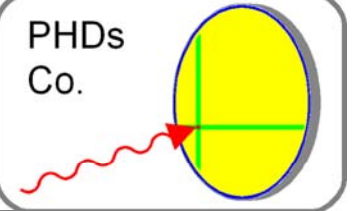


**A 1.5-mm diameter 1-pF p+
hole-collecting contact**

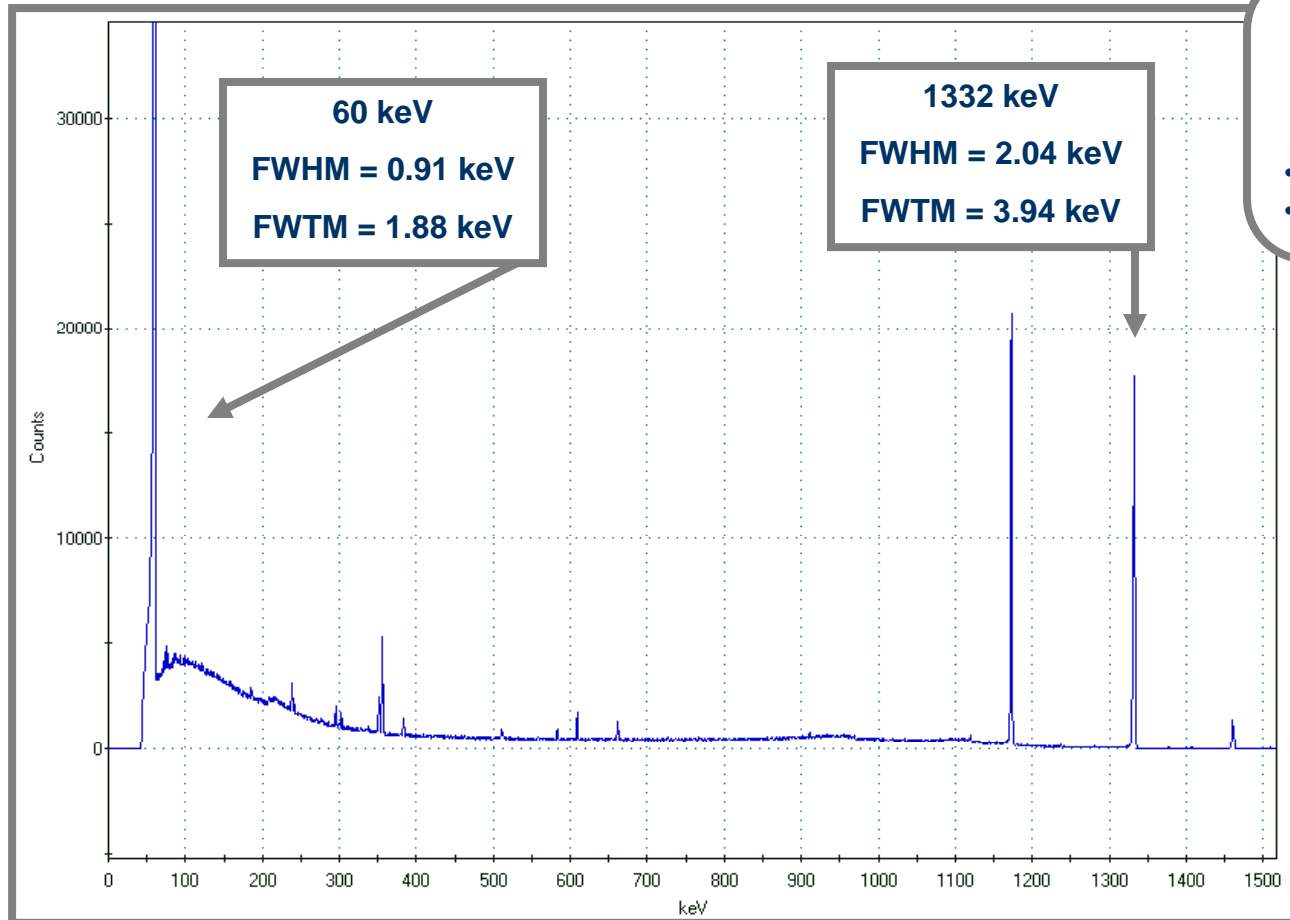
**Fabrication complexities
addressed:**

- 1. Grinding the small hole**
- 2. Placement of p+ contact
in the hole**
- 3. Controlling surface
leakage currents with
passivation and novel
contact geometries**

PHDs
Co.



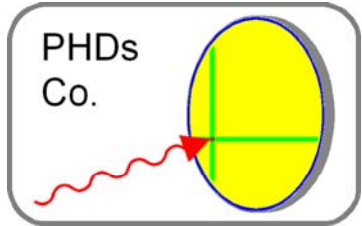
MJ70



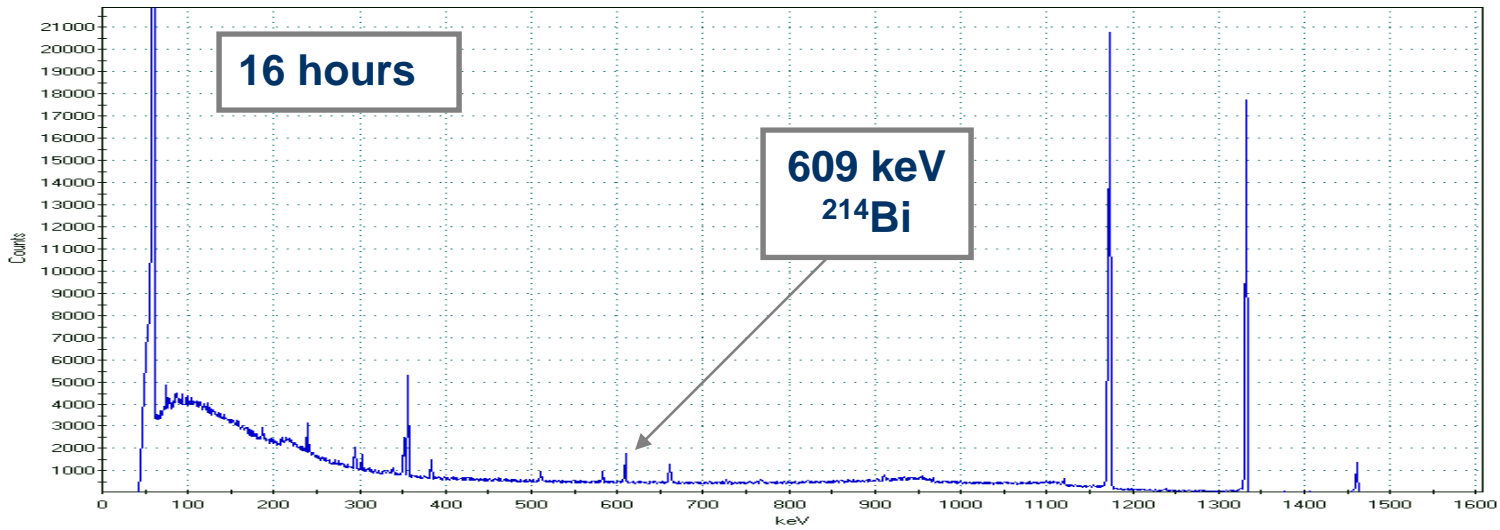
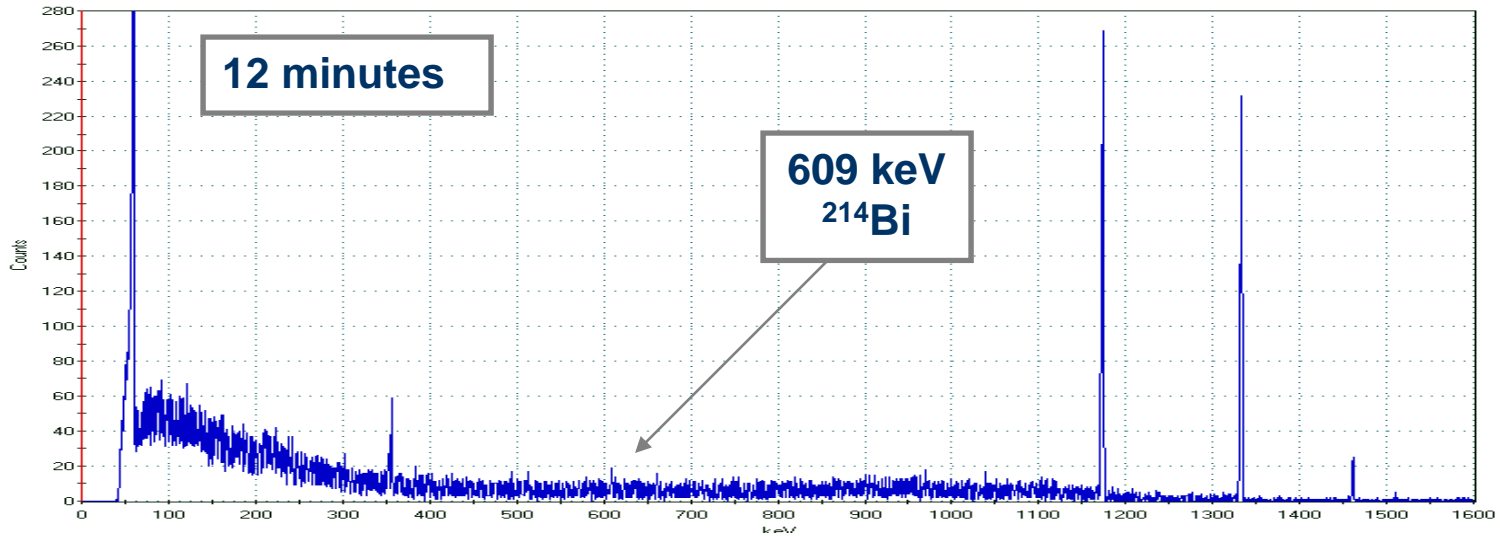
Surprisingly good spectroscopy
considering the extreme
detector geometry

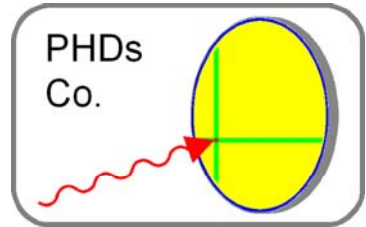
- No beveled corners
- Very small p+ contact



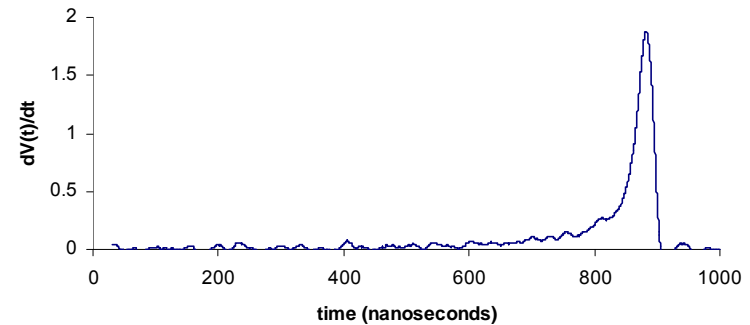
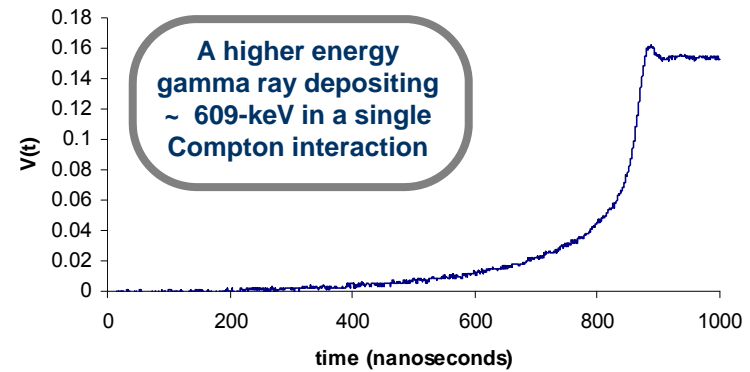
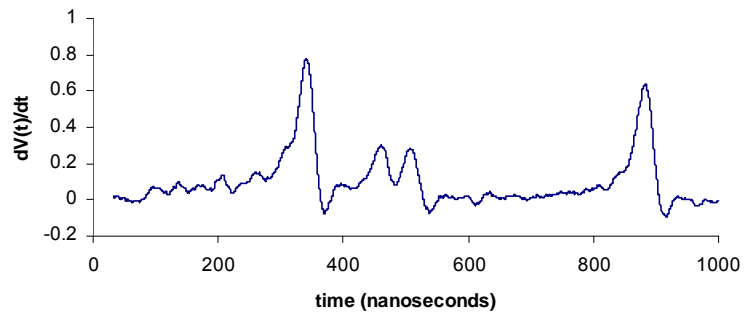
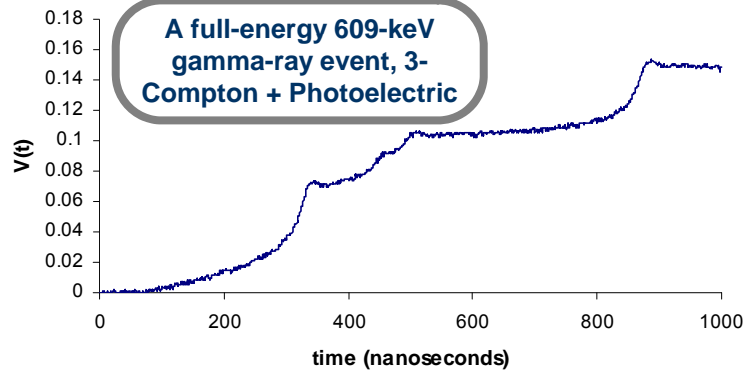
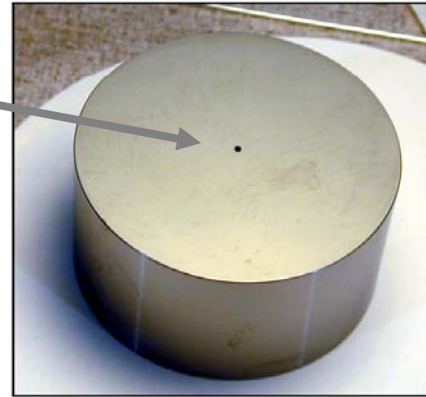


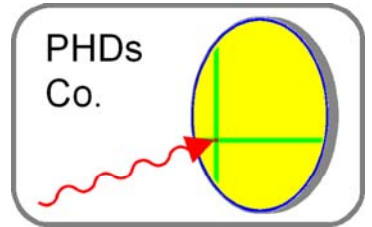
**Statistical counting limitations –
consider the 609-keV energy region**





The small hole makes individual gamma-ray interactions quite apparent in signals allowing additional background reduction.





Summary:

1. **NPX** (DE-FG02-03ER84742) and **NPX-M** (DE-FG02-05ER84501)
Germanium Strip Detector products
2. **MJX** (DE-FG02-05ER84157)
P-type point contact detector products

PHDs Co NP Phase-II SBIR Supported Efforts Have Created these Products by the end of Phase II

The DOE NP SBIR Program is a unique and essential resource for germanium detector physics and technology development.