Germanium-based detectors for gamma-ray imaging and spectroscopy

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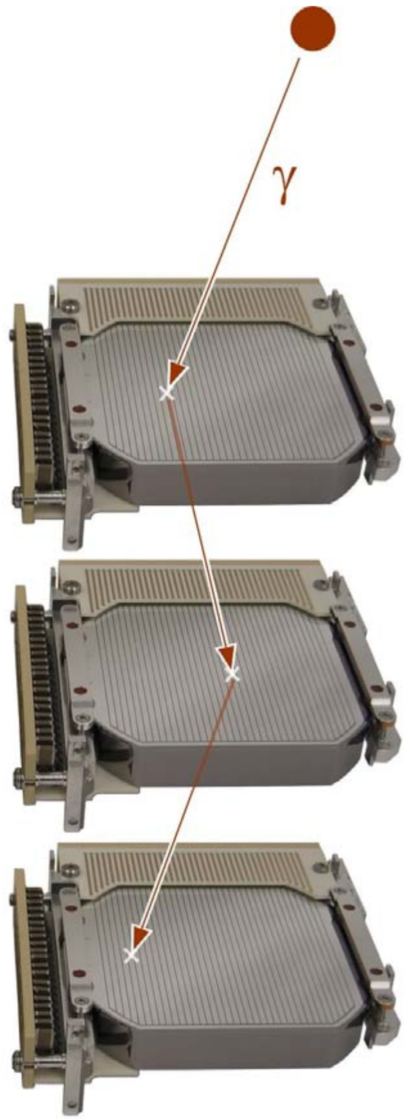
The Sixth International “Hiroshima” Symposium on the Development and Application of Semiconductor Tracking Detectors



Gamma-ray tracking

Outline

- Ge detectors and Gamma-ray imaging
- Detector fabrication technologies
- Amorphous-semiconductor contacts
- Bipolar blocking and barrier heights
- 3-d position detection
- Fine electrode segmentation
- Issues: charge sharing, temperature cycling

Detector material: Why Ge?

- High Z
- Large commercially available crystals
  10 cm diameter boules
- Large depletion lengths
  > 2 cm

} High efficiency

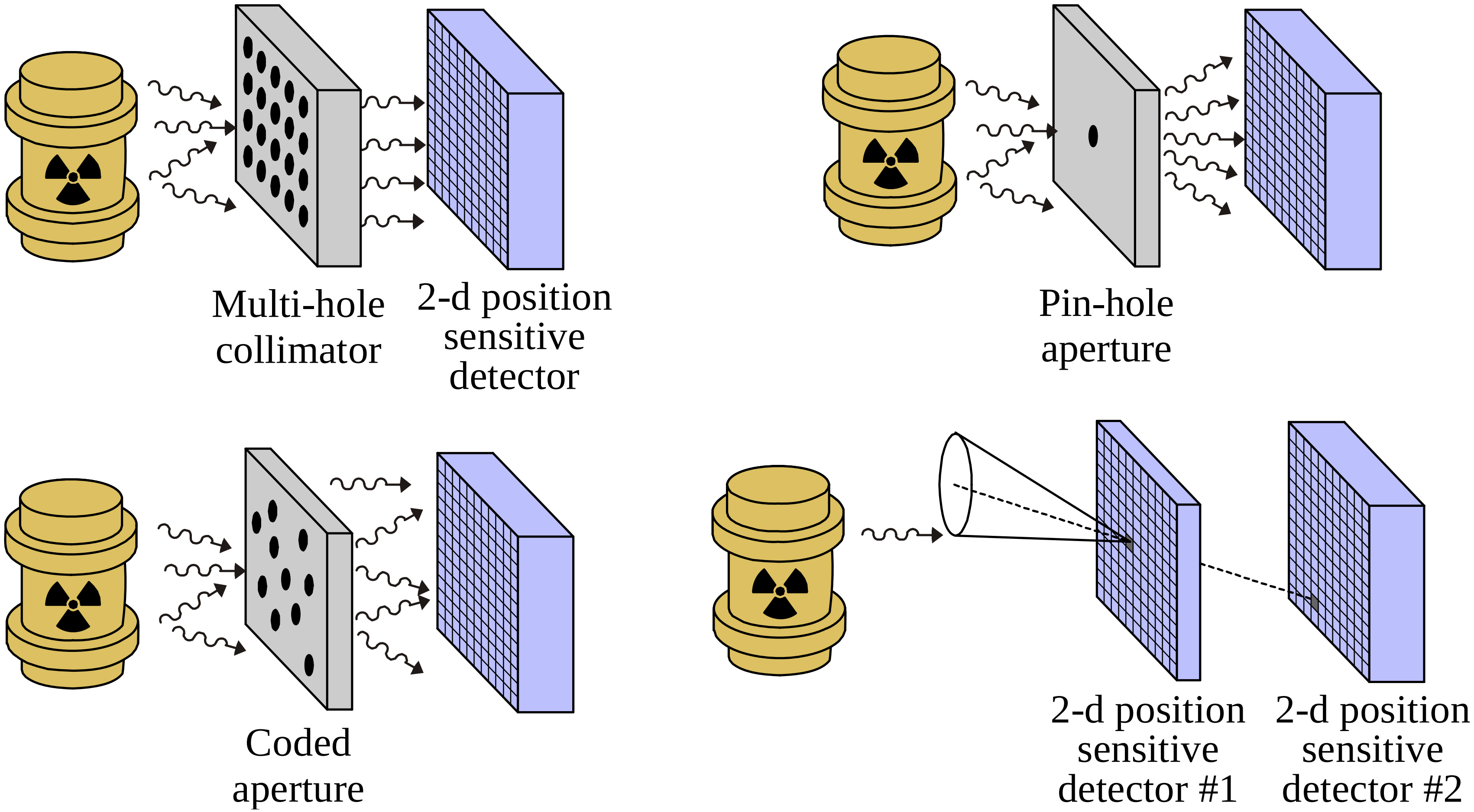
- Near perfect charge collection
  $\mu\tau_e$, $\mu\tau_h$ >10 cm^2/V → L > 10^4 cm
- Favorable charge generation statistics

$$\Delta E_{Statistics} = 2.35(F\varepsilon E_\gamma)^{1/2},$$
$$F \equiv \text{Ge Fano factor} = 0.08\,\text{eV}$$
$$\varepsilon \equiv \text{Ge e-h pair creation energy} = 2.97\,\text{eV}$$

} Excellent energy resolution
< 0.2%FWHM @ 1.3MeV

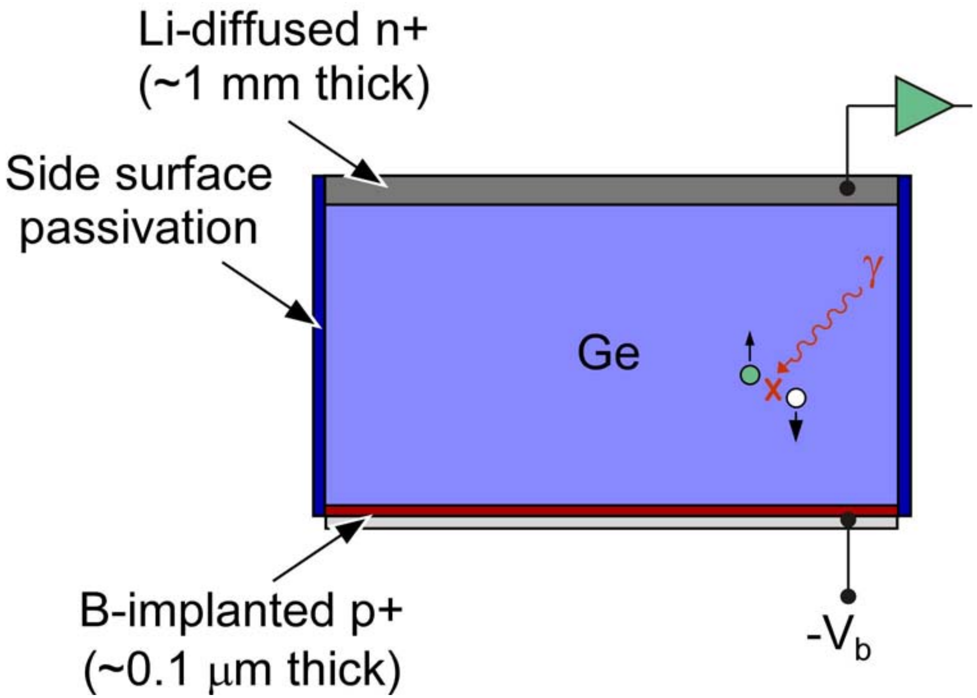
However, cooling to near LN temperatures required because of small band gap

Gamma-ray imaging



Need position as well as spectroscopic information

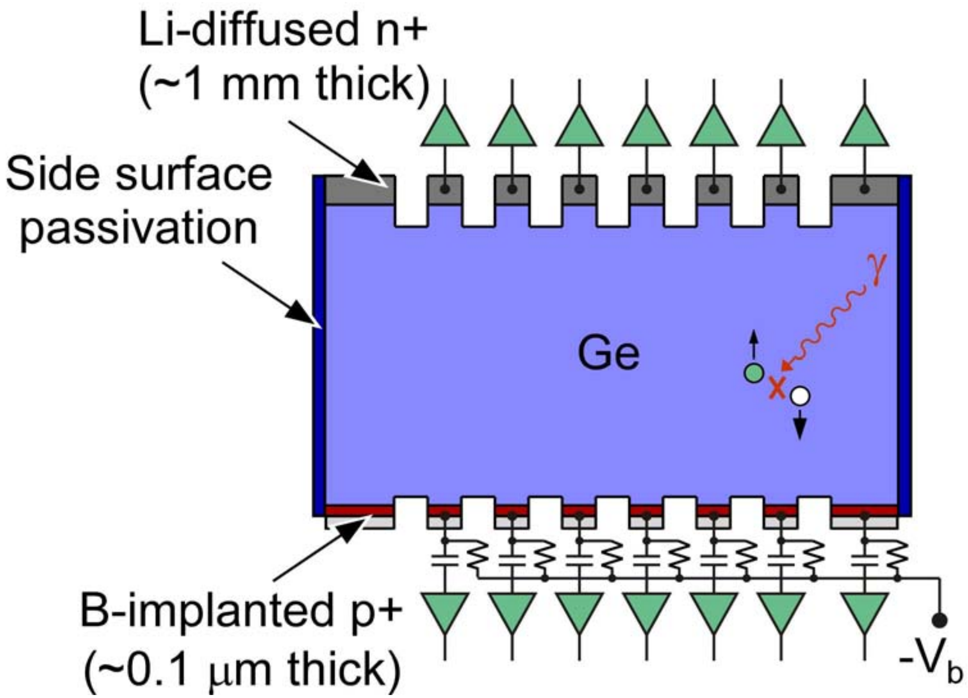
Standard Ge technology



Implanted n+ contacts do not withstand high fields and are not reproducible

Metal surface barrier contacts are not rugged and are p-type

Segmented electrical contacts

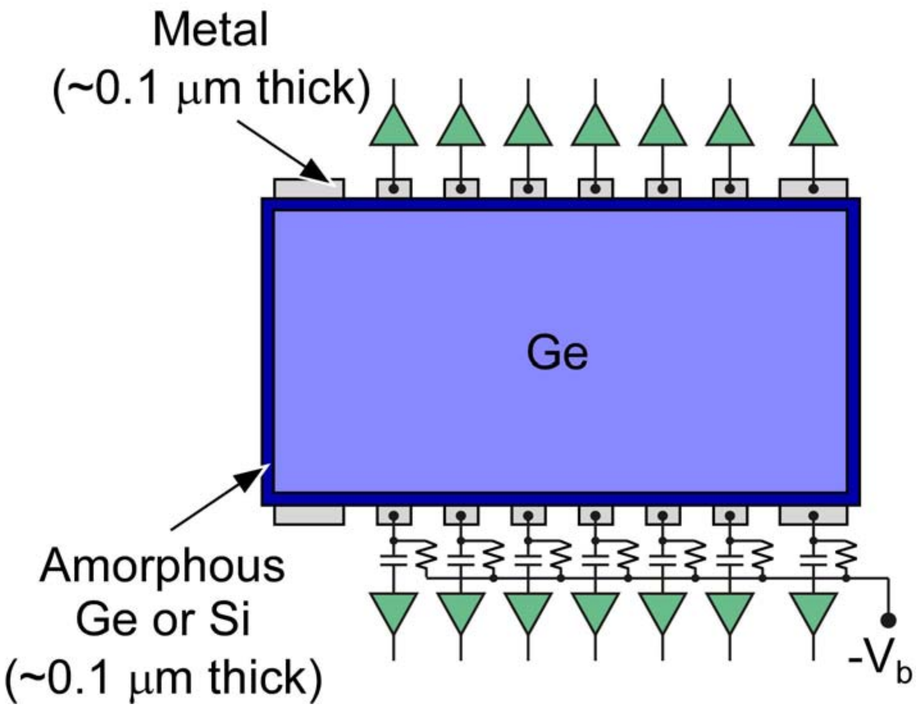


Problems:

- Thick Li and post fabrication diffusion limit pitch to ~ 1 mm
- Interstrip surfaces lack passivation

Fine pitches possible on B-implanted contact

Amorphous semiconductor contacts

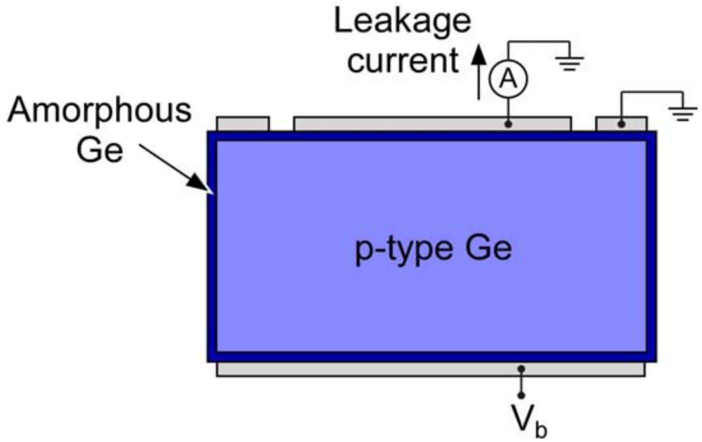


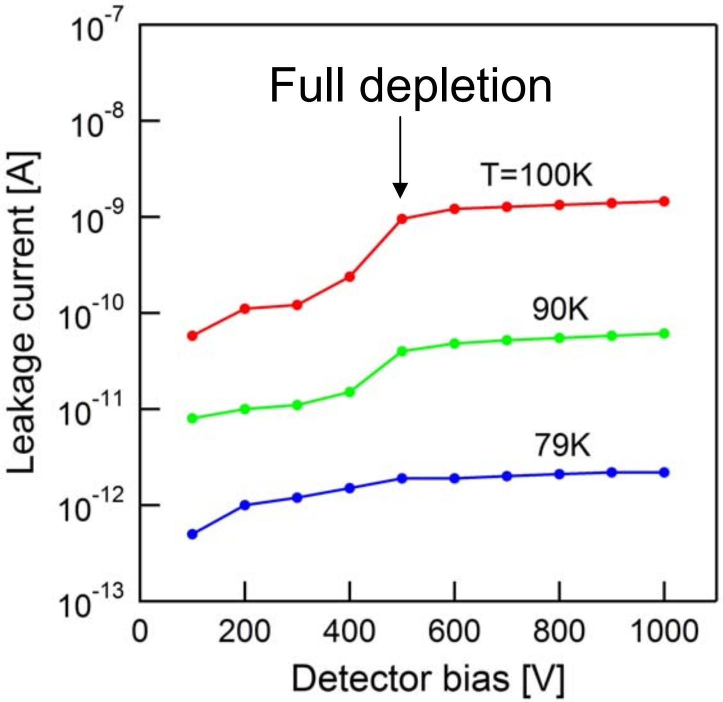
Advantages:

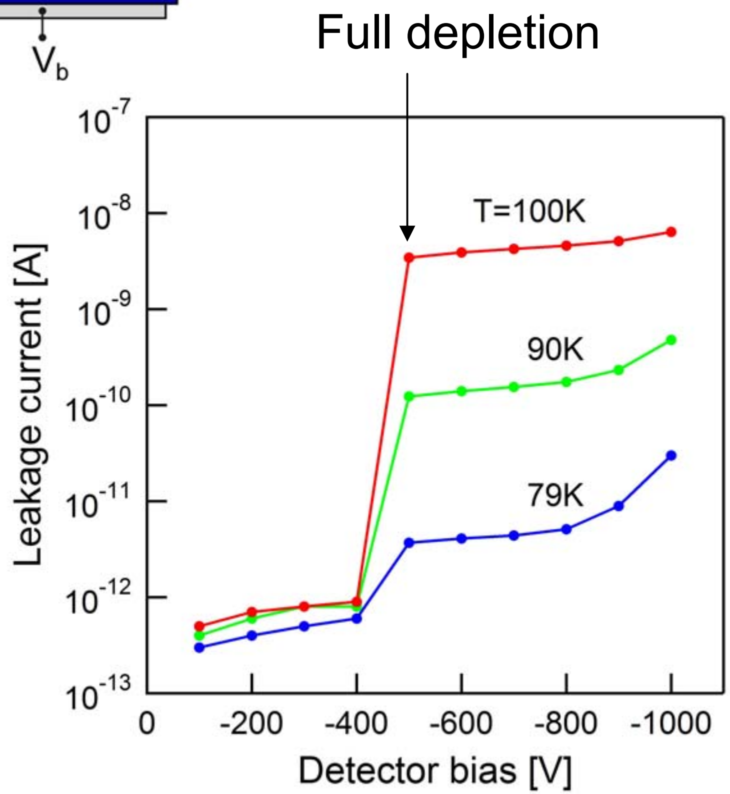
- Bipolar blocking contacts
- Self passivating
- Simple fabrication process
- Thin contact dead layer
- Fine pitches achievable

W. Hansen and E. Haller, IEEE TNS 24, 61 (1977).
P.N. Luke, et al., IEEE TNS 39, 590 (1992).

Bipolar blocking behavior

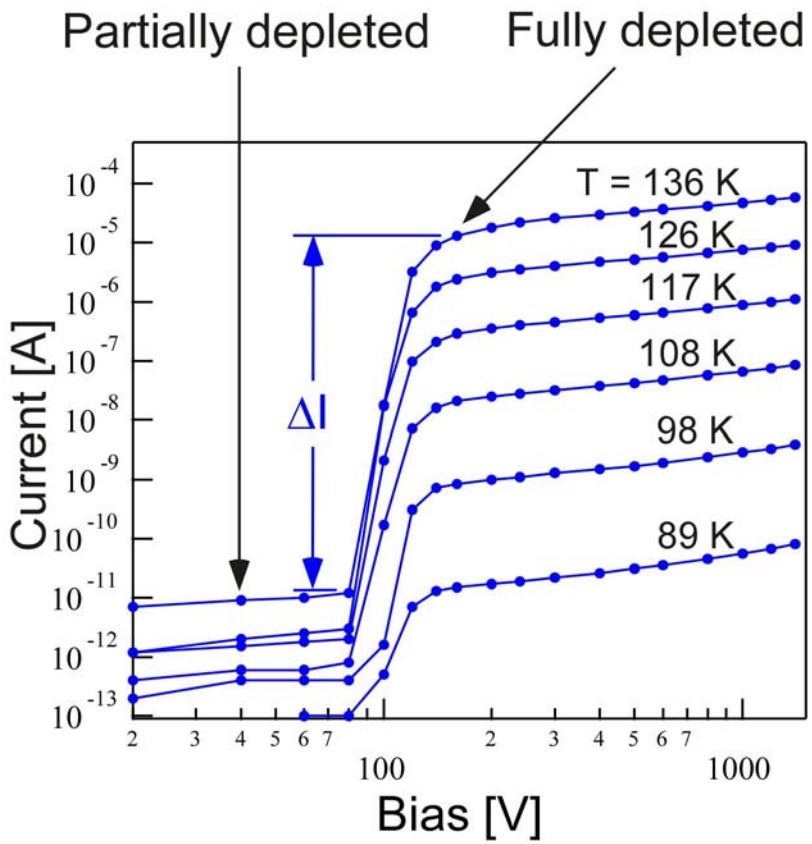




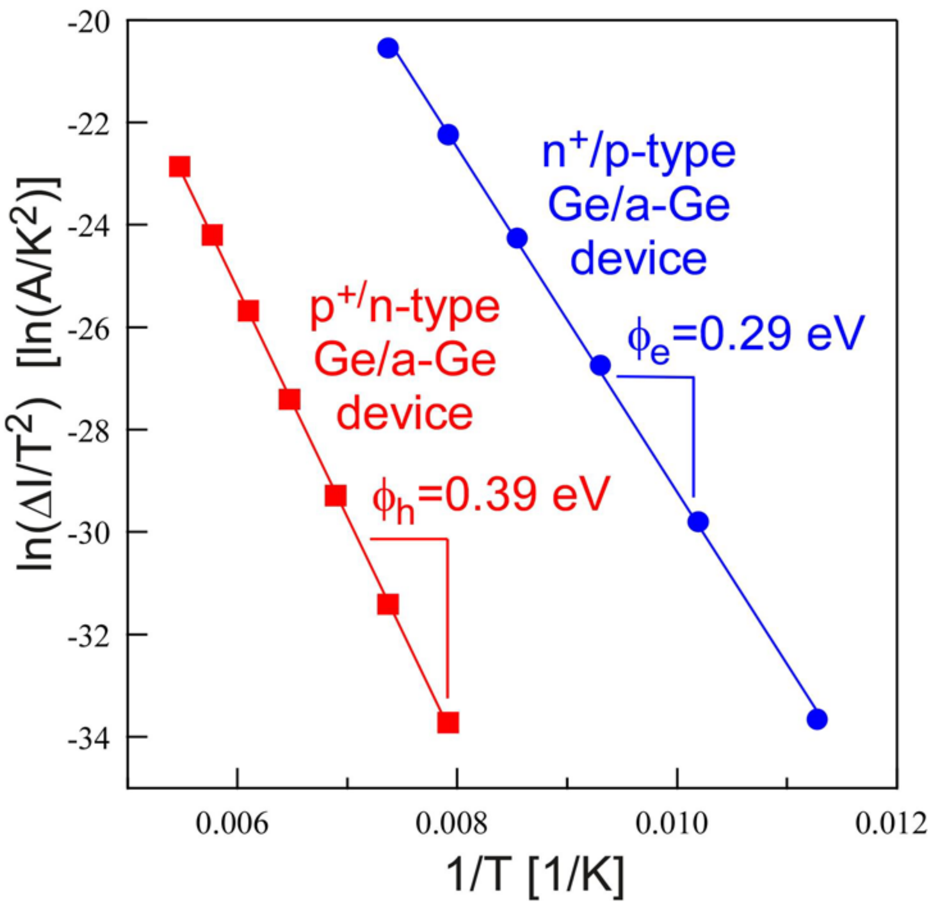


Barrier heights

n+ / p-type Ge / a-Ge device



Fit to $\Delta I = AT^2 e^{-\phi/kT}$



Barrier heights

Contact	ϕ_e [eV]	ϕ_h [eV]	$\phi_e + \phi_h$ [eV]	ρ [Ω-cm]
a-Ge (Ar)	0.36	0.34	0.70	$\sim 10^6 - 10^8$
a-Ge (Ar+17.5% H_2)	0.29	0.39	0.68	$\sim 10^{11}$
a-Si (Ar)	0.39	0.28	0.67	

Barrier heights depend on material and deposition parameters

Higher film resistivity of a-Ge (Ar+17.5% H_2) over that of a-Ge (Ar) typically desired to obtain high inter-electrode impedance

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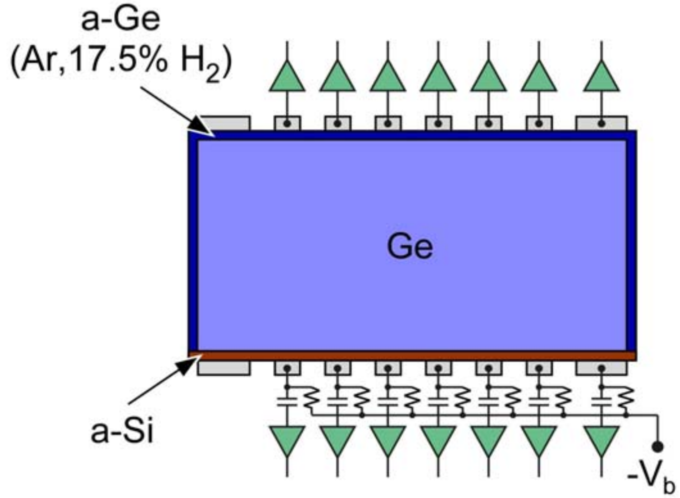
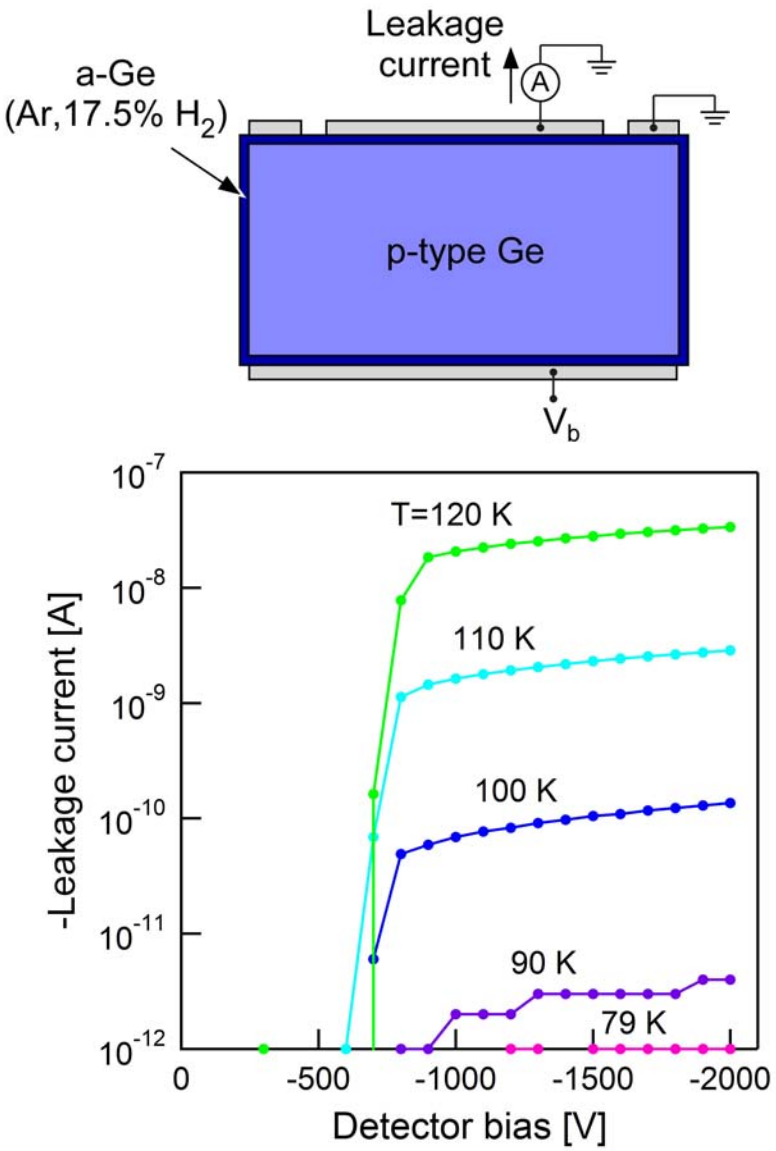
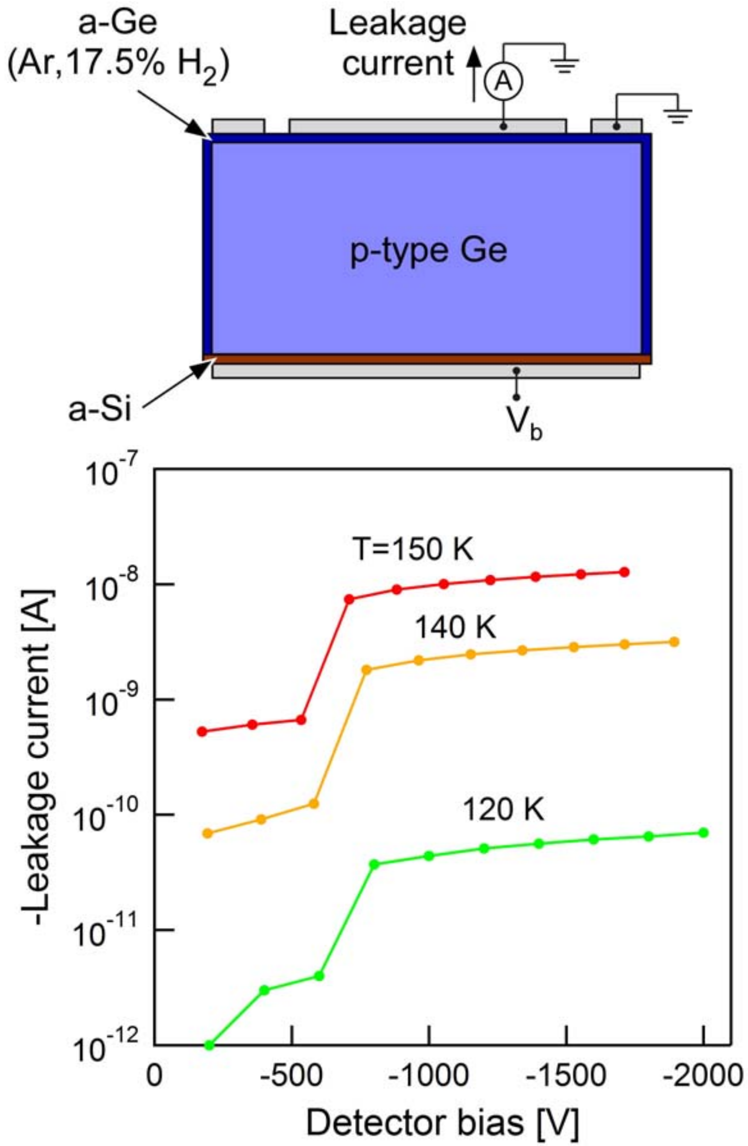
Choose this combination to minimize leakage current

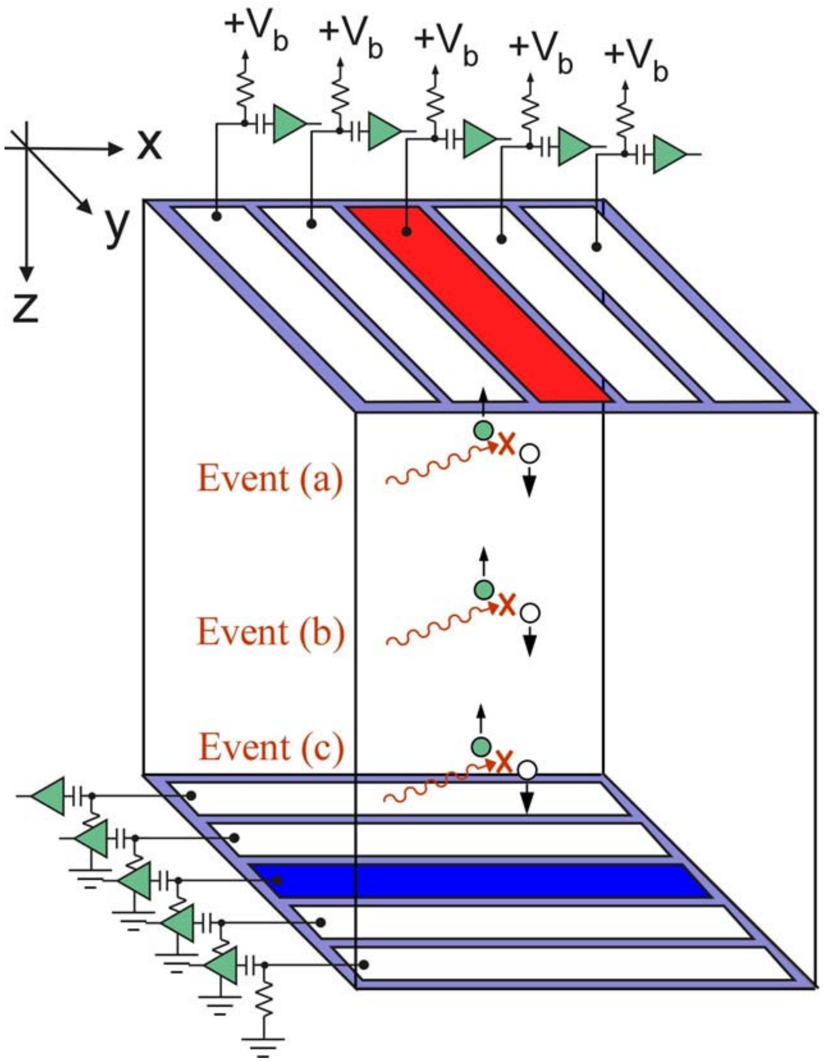


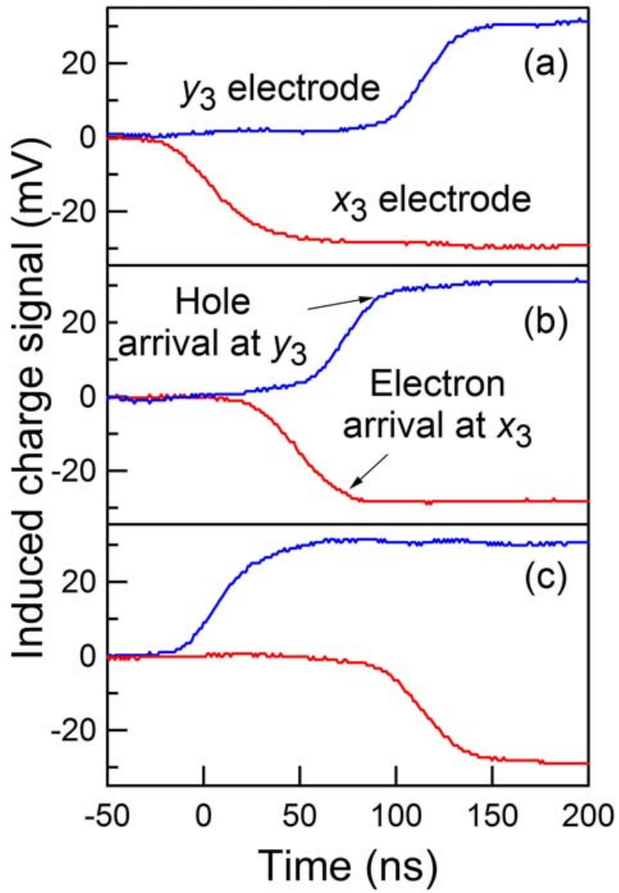
Barrier heights





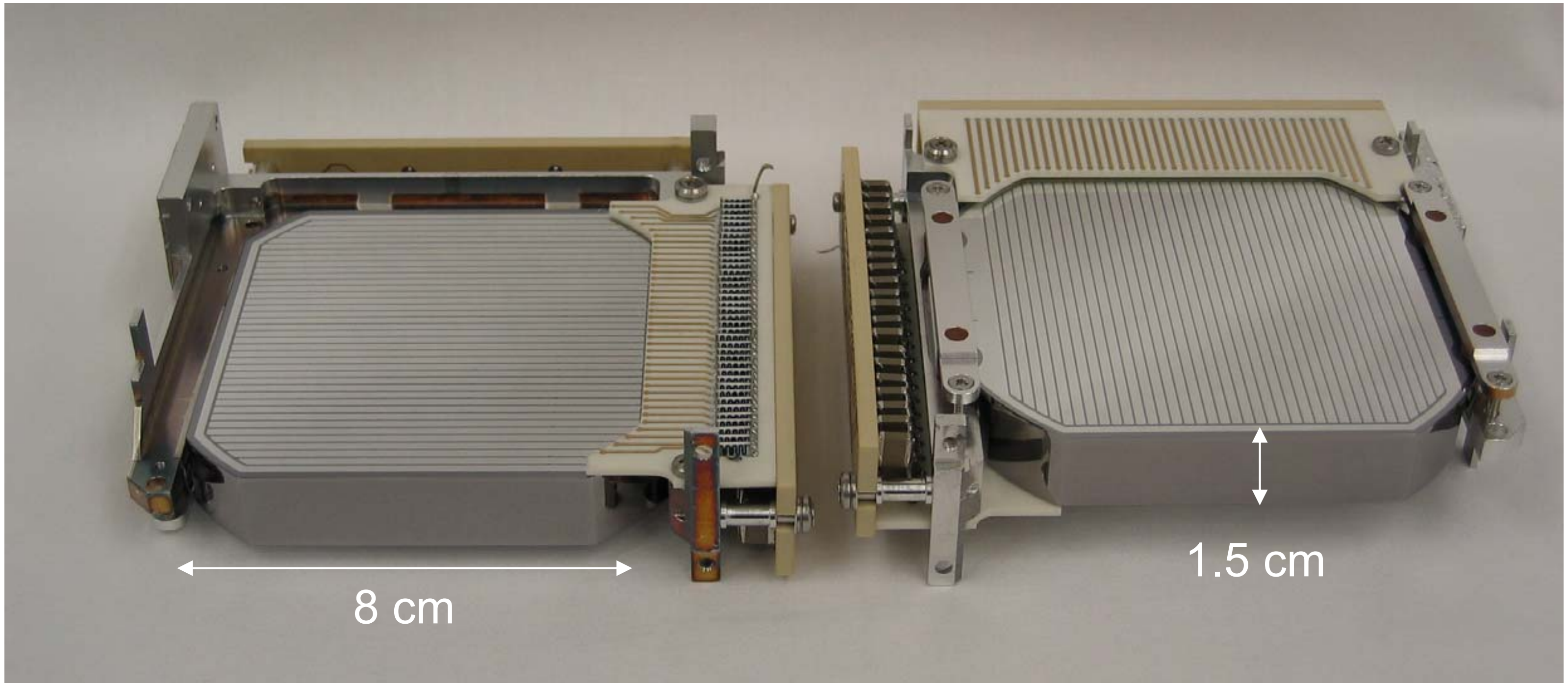
3-d position detection





M. Momayezi, et al., SPIE 3768, 530 (1999).
M. Amman and P.N. Luke, NIM A 452, 155 (2000).

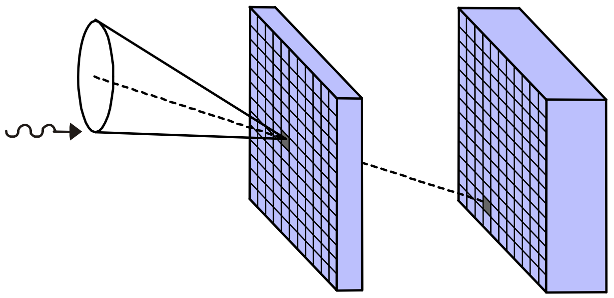
Detector example

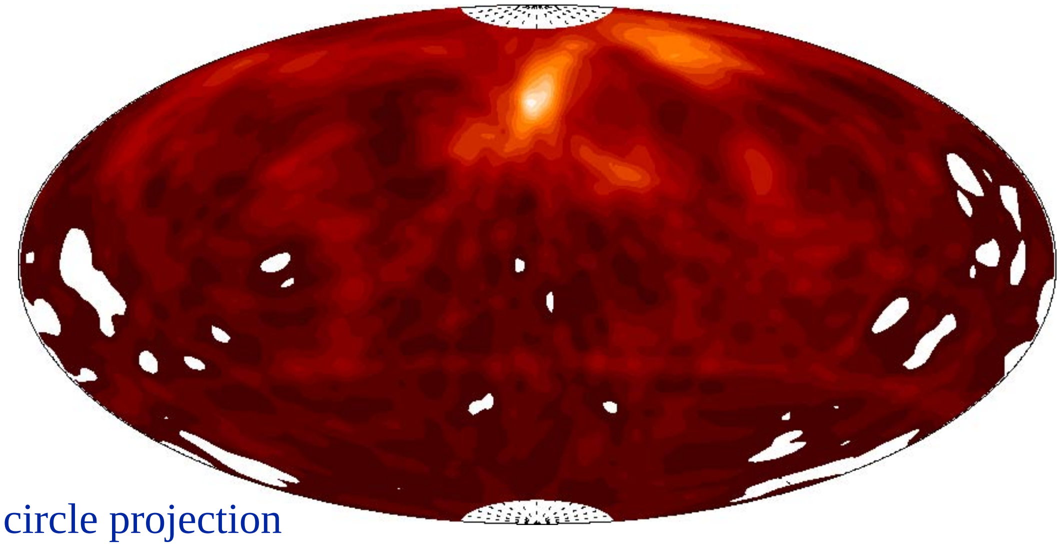


Orthogonal-strip detectors produced for the Nuclear Compton Telescope (Steve Boggs at UC Berkeley Space Sciences Laboratory)

37 strips each side, 2 mm strip pitch, a-Ge (Ar, 17.5% H_2) contacts
6 detectors produced to date (12 ultimately required)

Detector example





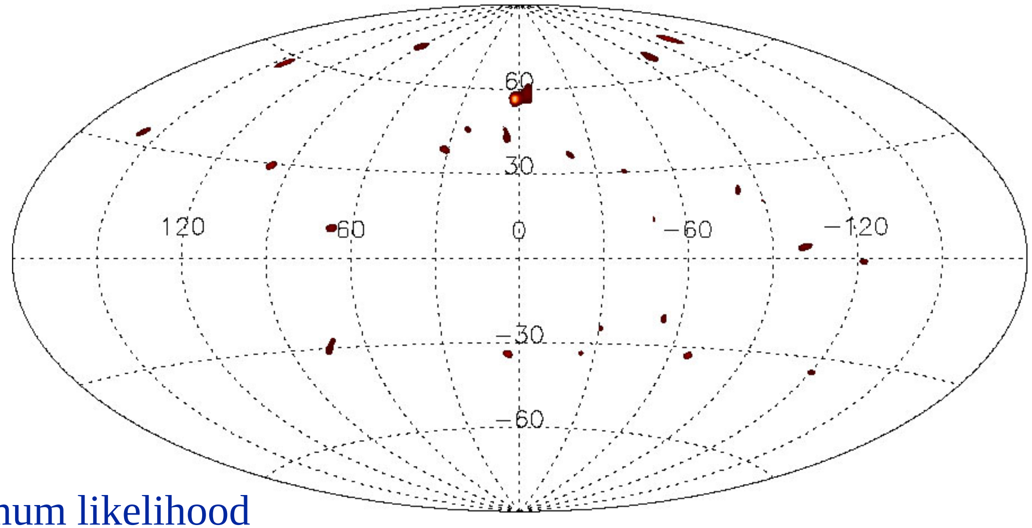
Compton circle projection

NCT Prototype

^{60}Co (1.173 MeV) source

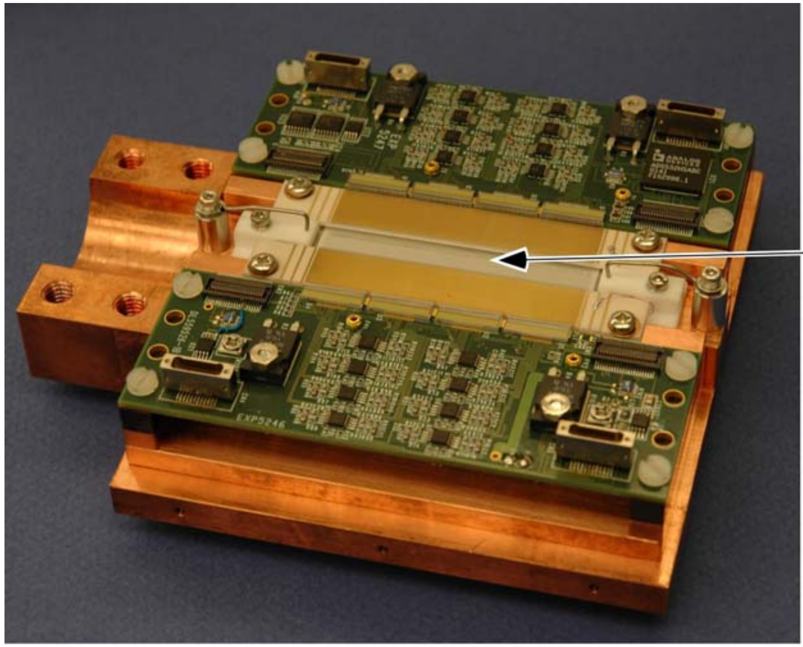
(50 μCi, 5 m, ~2 hrs.)

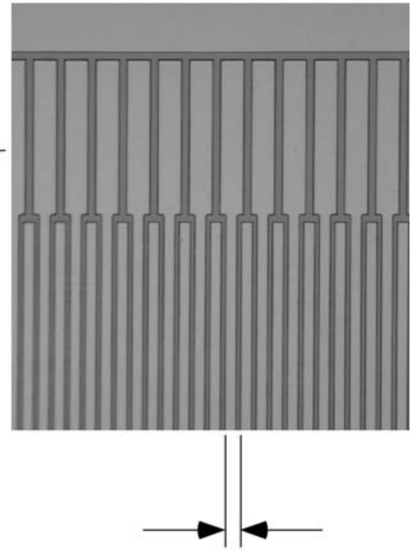
Courtesy: Steve Boggs, SSL



Maximum likelihood

Fine-pitched segmentation

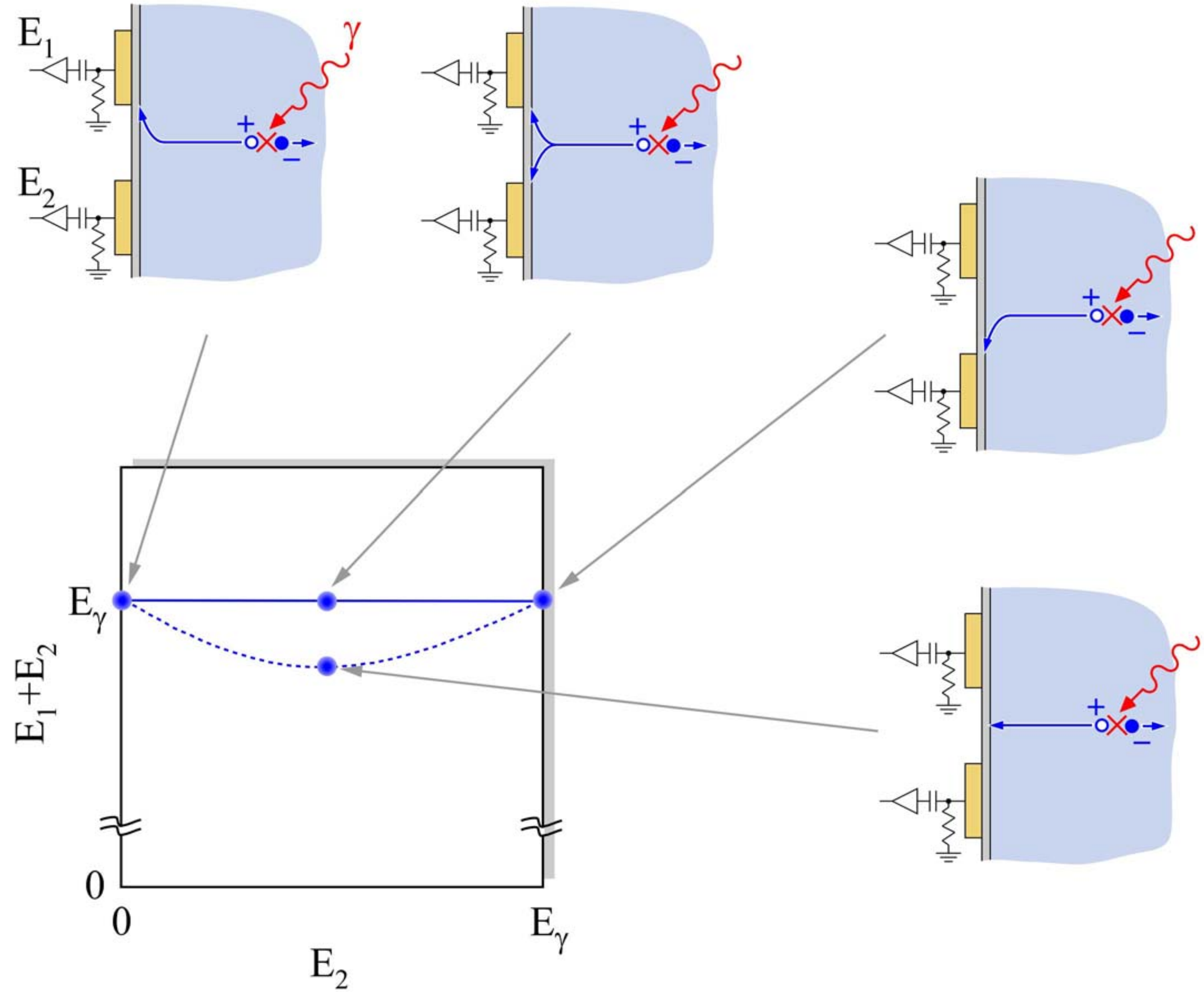




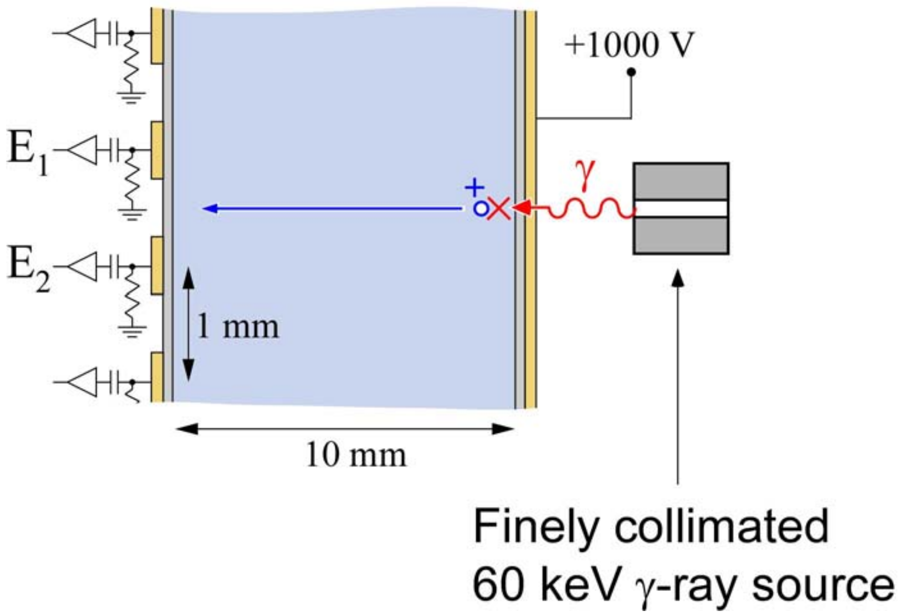
Strip detector produced for synchrotron x-ray applications (Daresbury Laboratory)

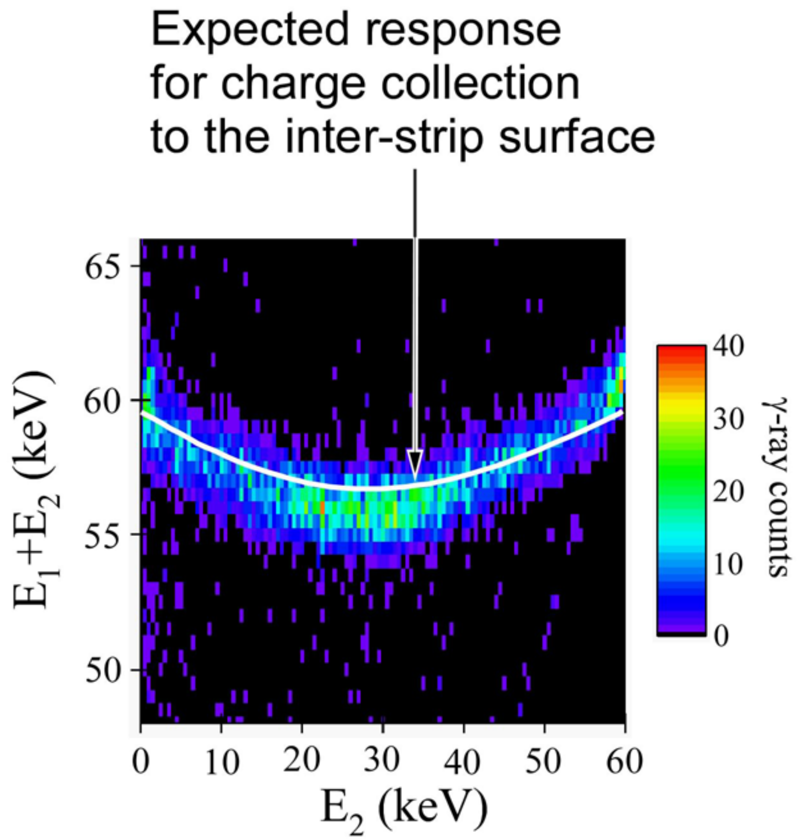
1024 strips, 50 μm strip pitch, 1 mm thick

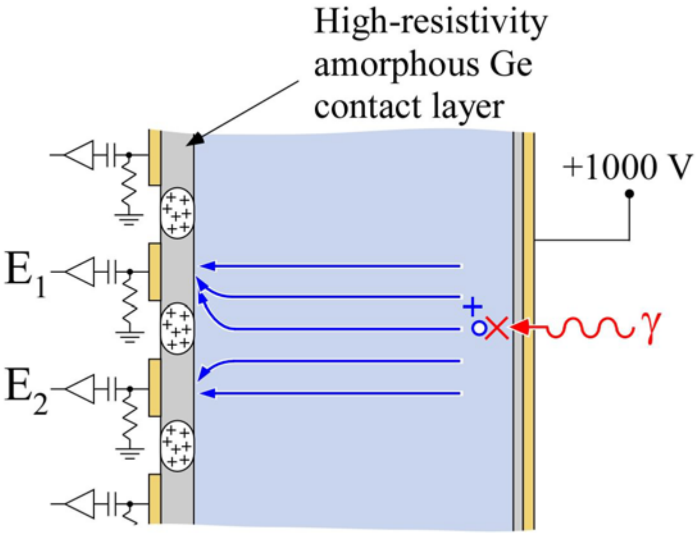
Issue: Charge sharing

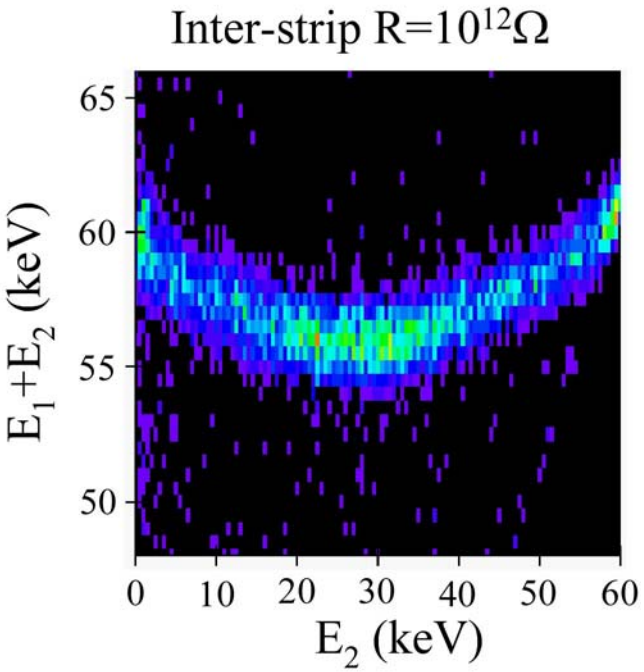


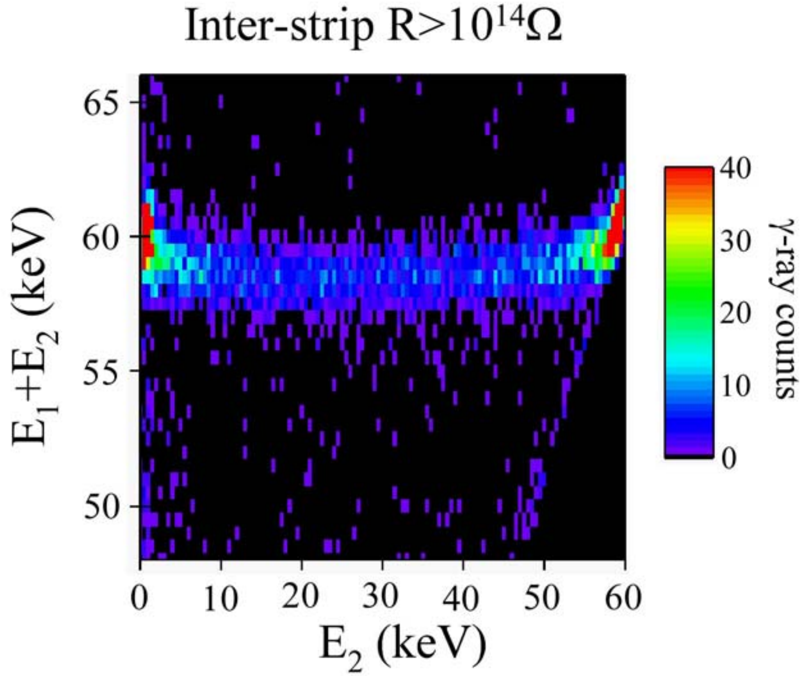
Issue: Charge sharing











Other solutions:

- Smaller gaps
- Field shaping electrodes: M. Amman and P.N. Luke, NIM A 452, 155 (2000).
- Etch away amorphous layer between electrodes: D. Protic and T. Krings, IEEE TNS 50, 998 (2003).

More work to be done …

Improvements needed

- Temperature cycling stability
- Optimization of a-Ge/Ge/a-Si configuration
- Charge sharing reduction
- Side surface state control?