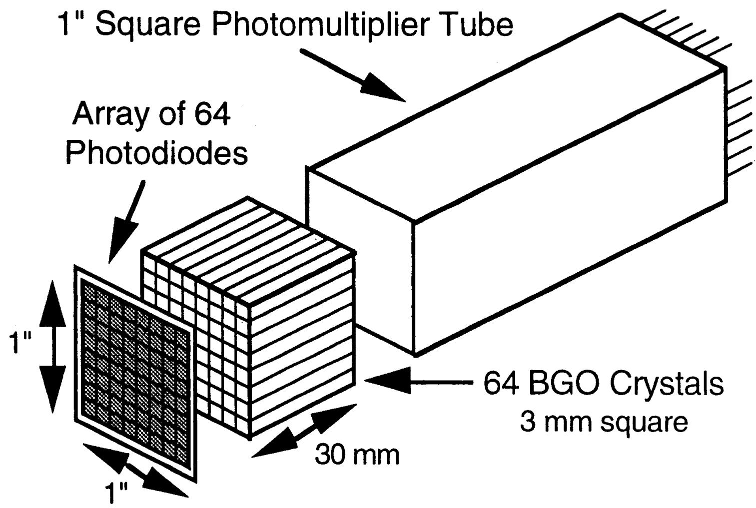
V.5. Semiconductor Detectors - Examples

1. Photodiode Readout

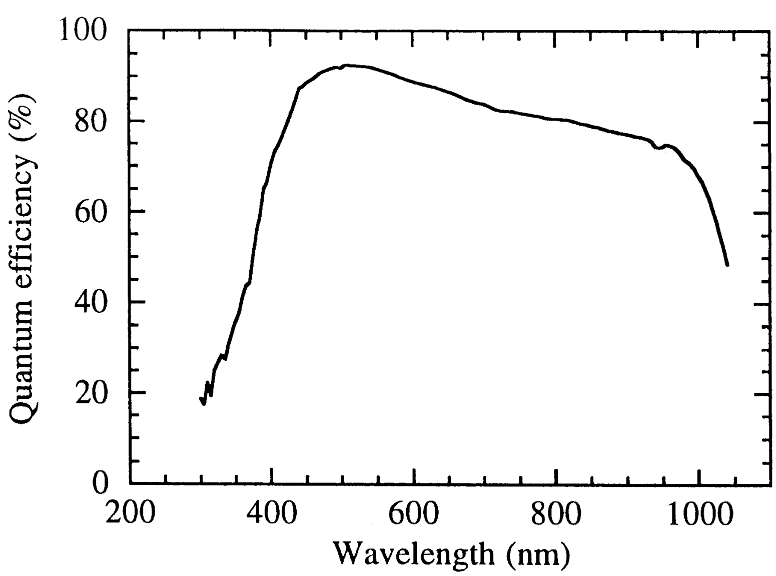
(S. Holland, N. Wang, I. Kipnis, B. Krieger, W. Moses, LBNL)

Medical Imaging (Positron Emission Tomography)



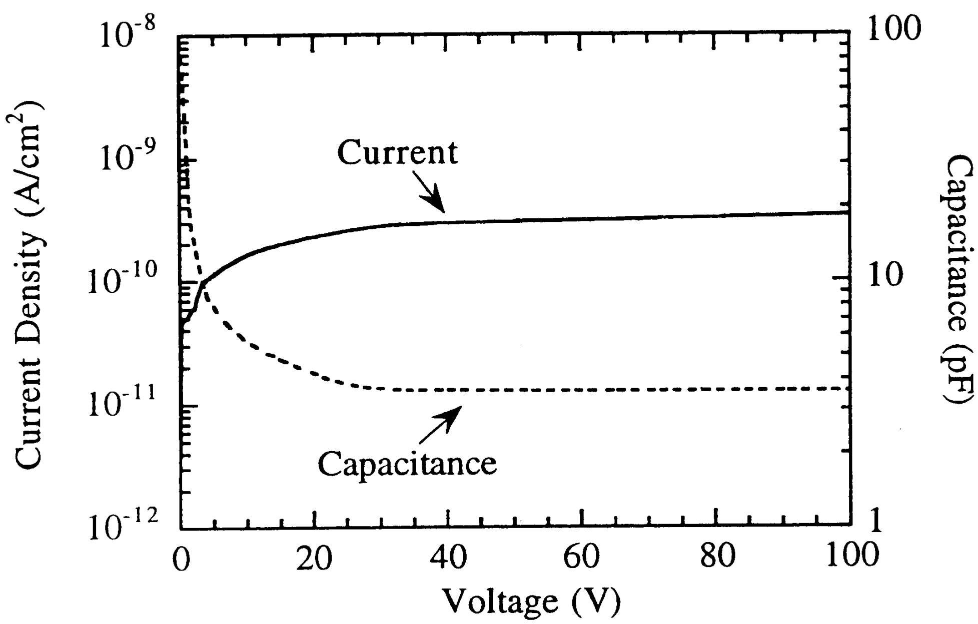
Read out 64 BGO crystals with one PMT (timing, energy) and tag crystal by segmented photodiode array.

Requires then dead layer on photodiode to maximize quantum efficiency.



Thin electrode must be implemented with low resistance to avoid significant degradation of electronic noise.

Furthermore, low reverse bias current critical to reduce noise.



Photodiodes designed and fabricated in LBNL Microsystems Lab.

Front-end chip (preamplifier + shaper):

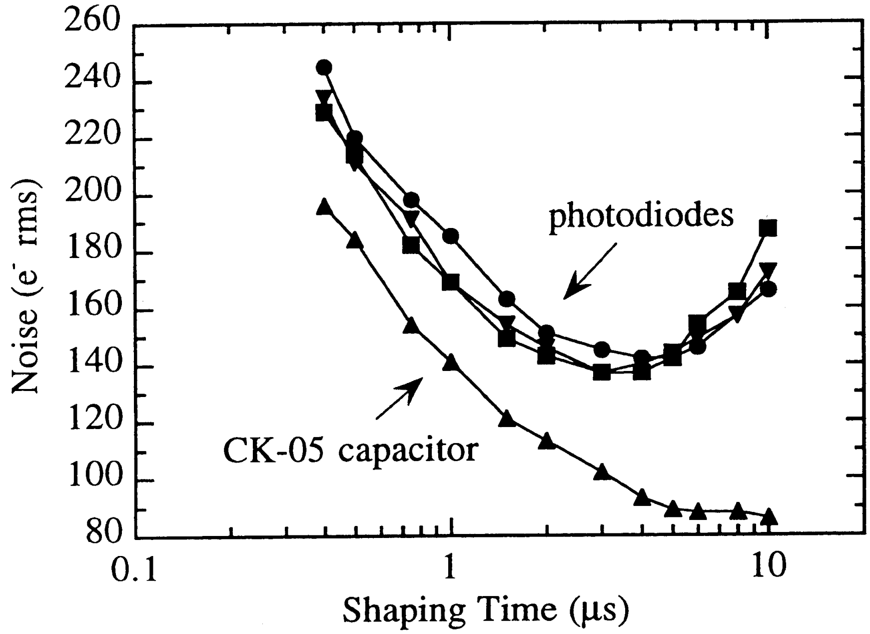
16 channels per chip

die size: 2×2 mm^2,
1.2 µm CMOS

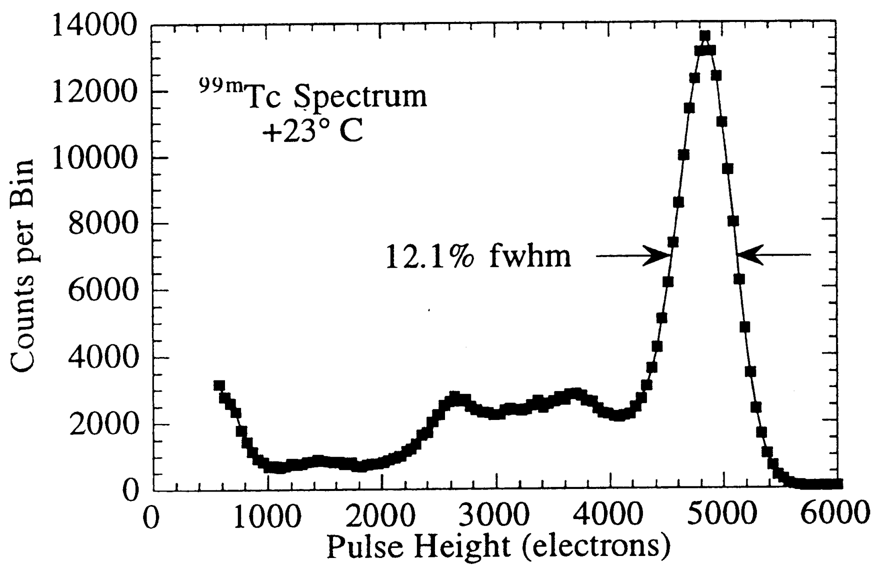
continuously adjustable shaping time (0.5 to 50 µs)

gain: 100 mV per 1000 el.

Noise vs. shaping time



Energy spectrum with BGO scintillator



2. High-Rate X-Ray Spectroscopy

(B. Ludewigt, C. Rossington, I. Kipnis, B. Krieger, LBNL)

Use detector with multiple strip electrodes

not for position resolution

but for

segmentation ⇒ distribute rate over many channels

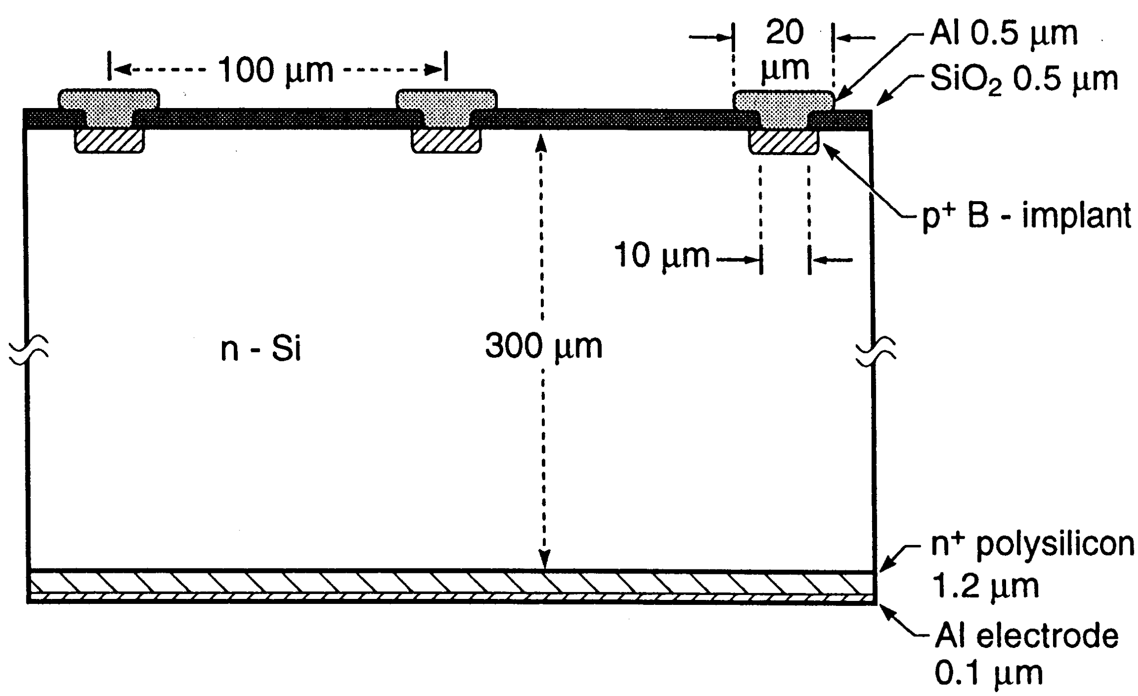
⇒ reduced capacitance

⇒ low noise at short shaping time

⇒ higher rate per detector element

For x-ray energies 5 – 25 keV ⇒ photoelectric absorption dominates (signal on 1 or 2 strips)

Strip pitch: 100 μm   Strip Length: 2 mm (matched to ALS)

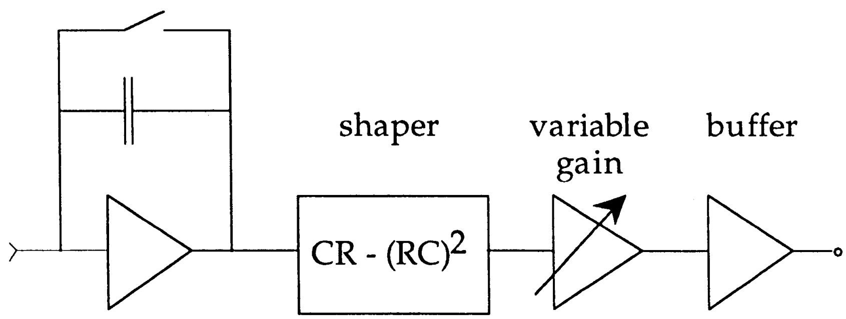


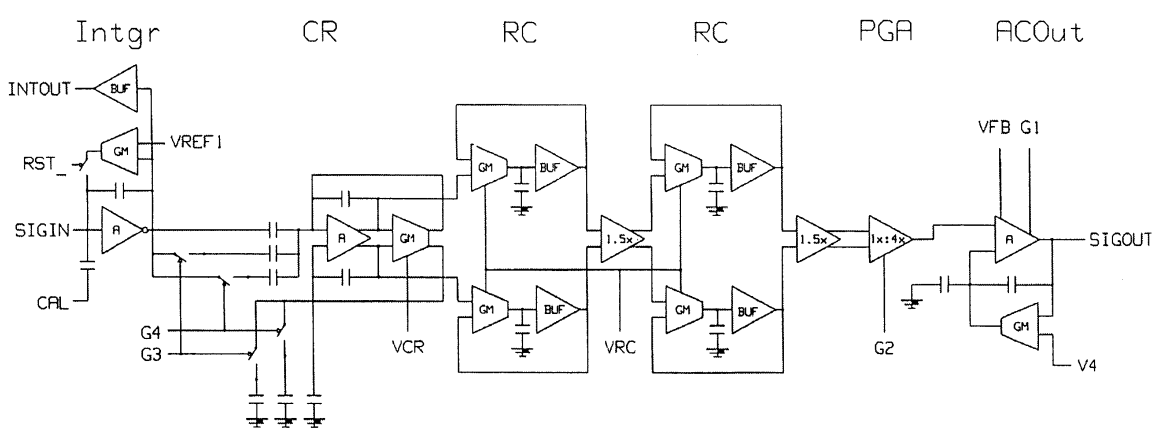
Readout IC tailored to detector

Preamplifier + CR-RC^2 shaper + cable driver to bank of parallel ADCs
(M. Maier + H. Yaver)

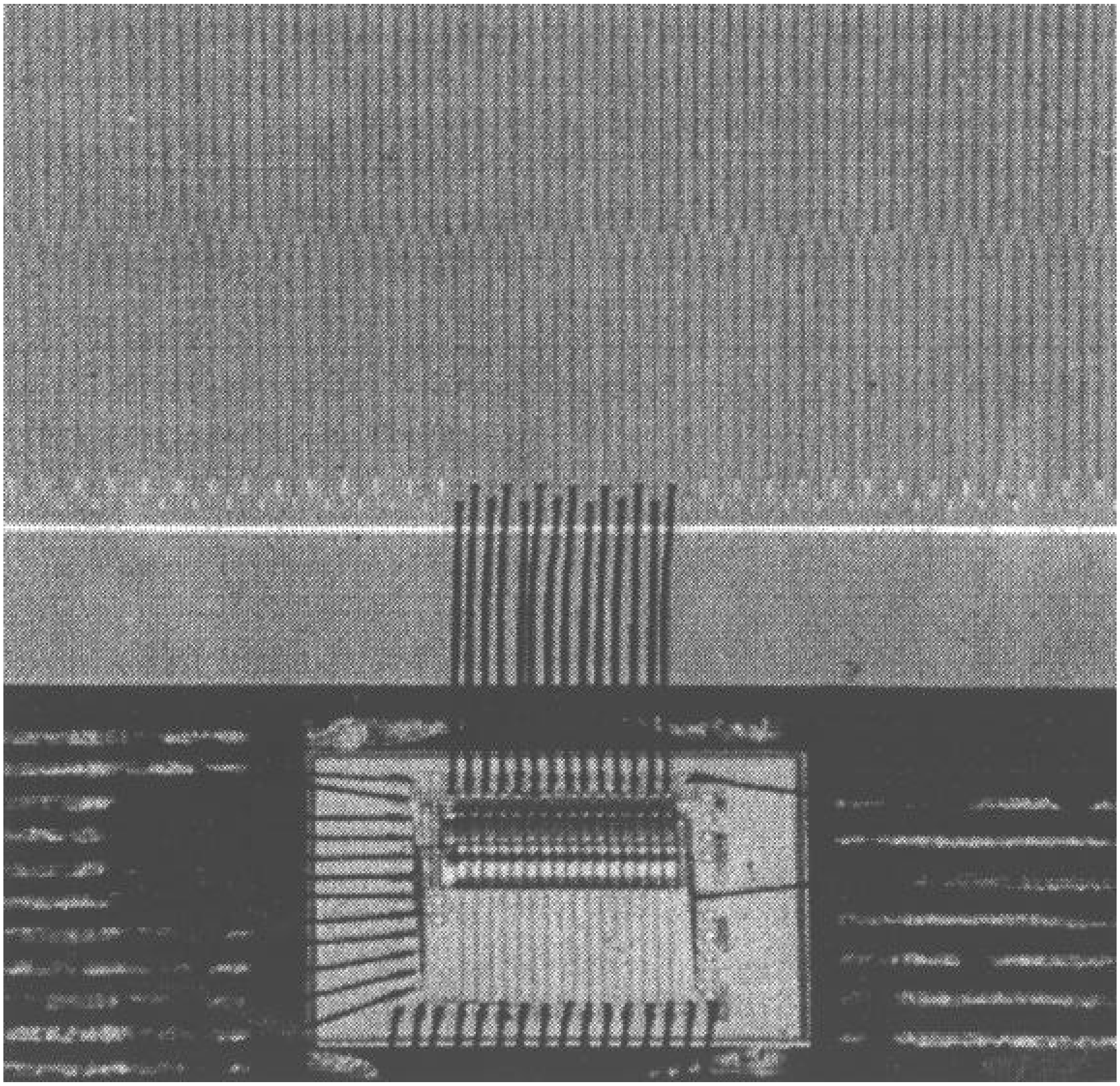
Preamplifier with pulsed reset.

Shaping time continuously variable 0.5 to 20 μs.

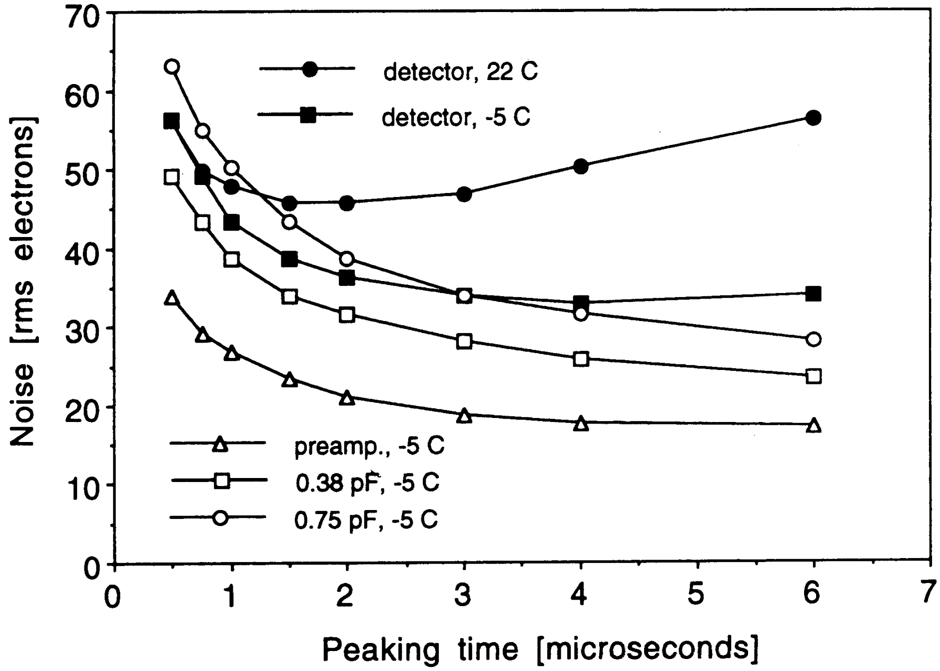




Chip wire-bonded to strip detector

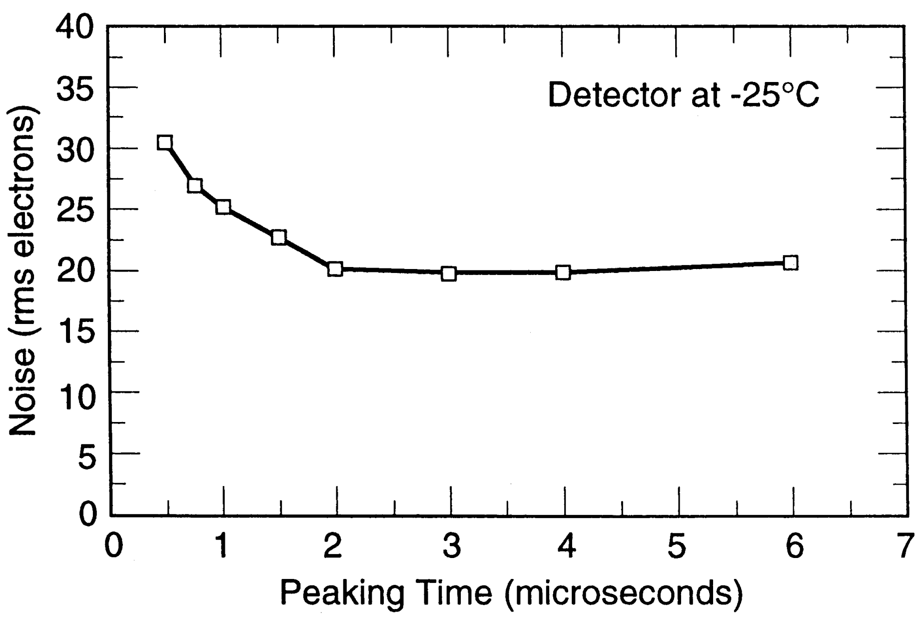


Initial results



Detector shot noise requires moderate cooling of detector.

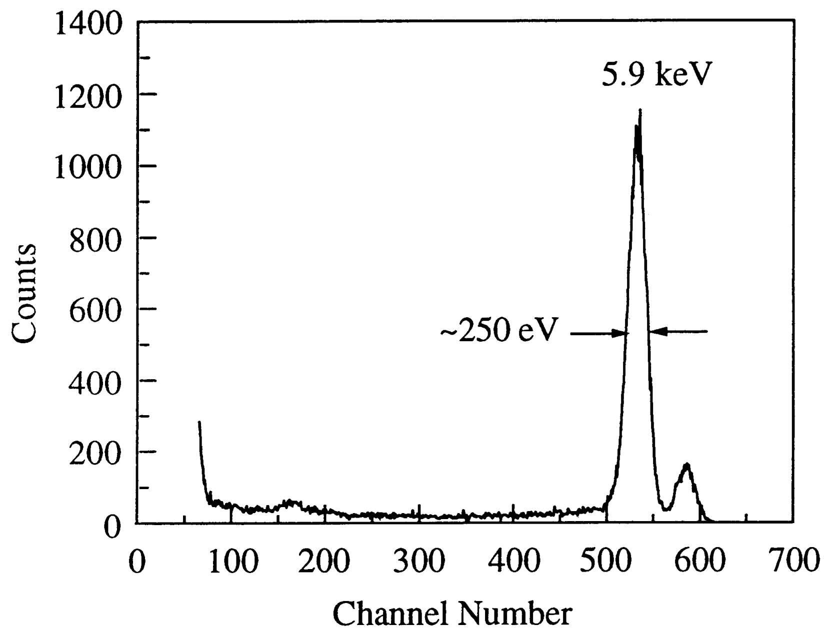
Second prototype



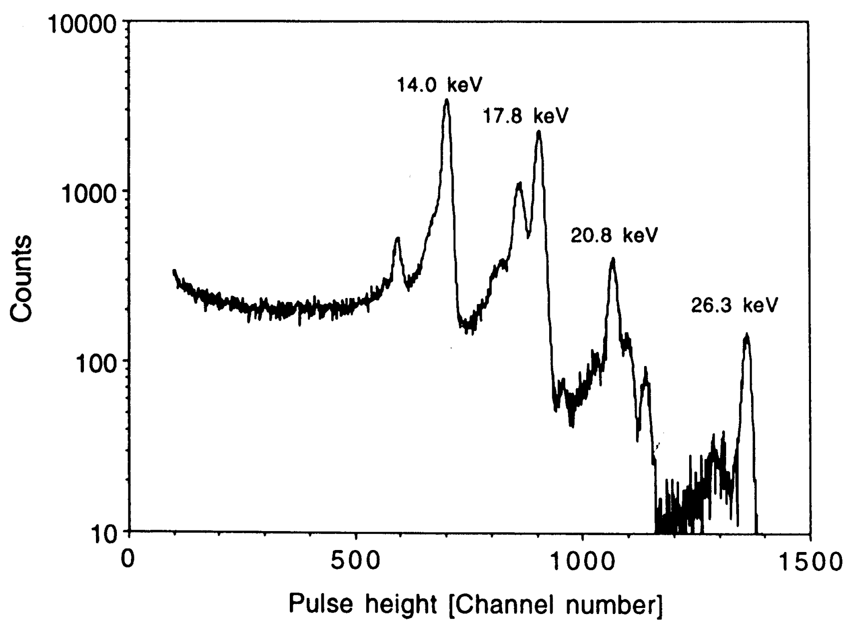
Current noise negligible – beyond 2 μs dominated by $1/f$ noise.

Measured spectra

^{55}Fe

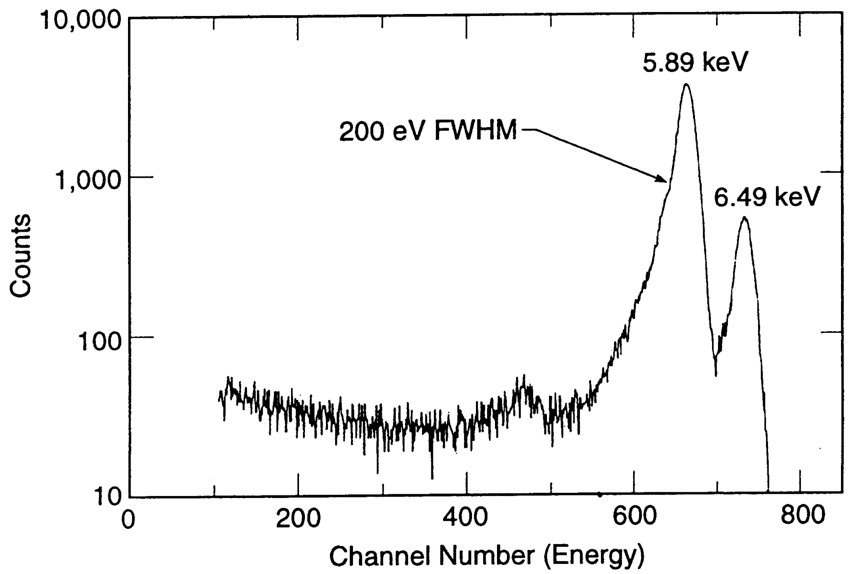


^{241}Am

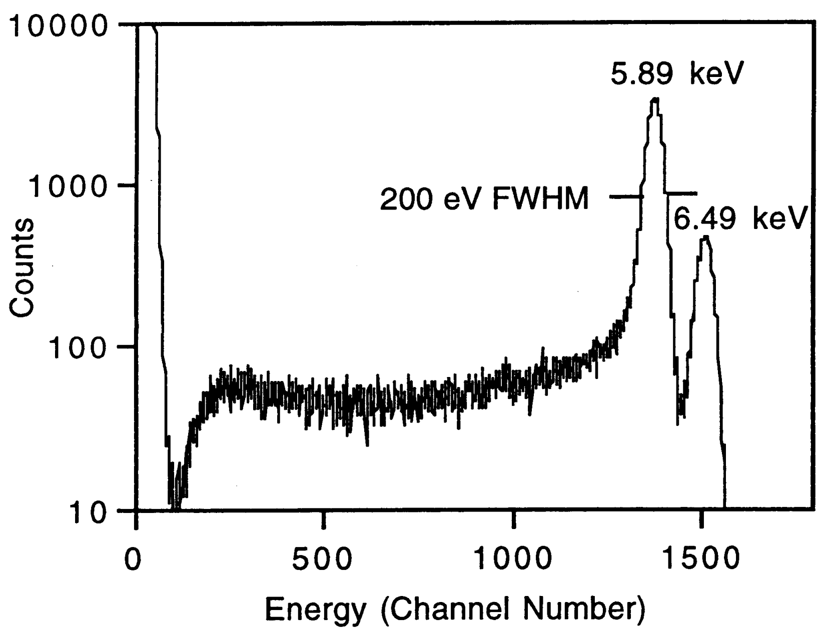


Some detector optimization still necessary

Backside incidence



Strip-side incidence



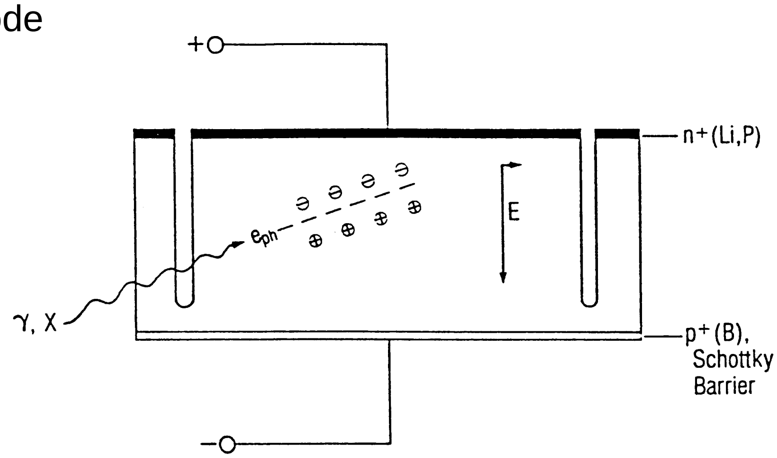
3. Large Volume Ge Detectors for γ- Spectroscopy

Typical configurations

5 – 10 cm diameter, up to 400 cm^3 volume

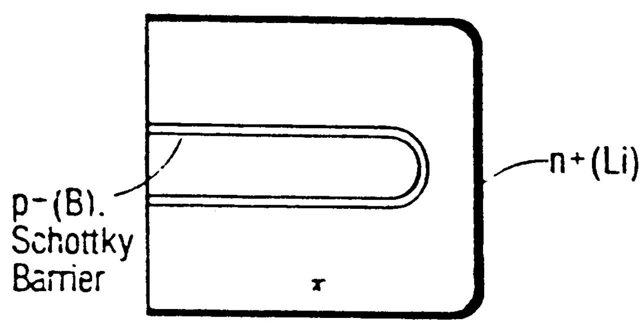
Use *p-i-n* structure, where bulk is very lightly doped.

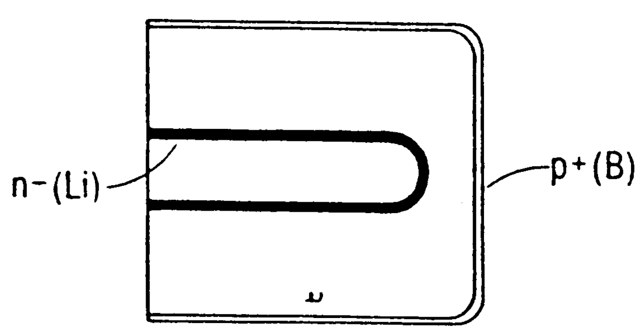
Planar Diode



Grooves at edge define active area and isolate it from outer surface.

Coaxial Diodes



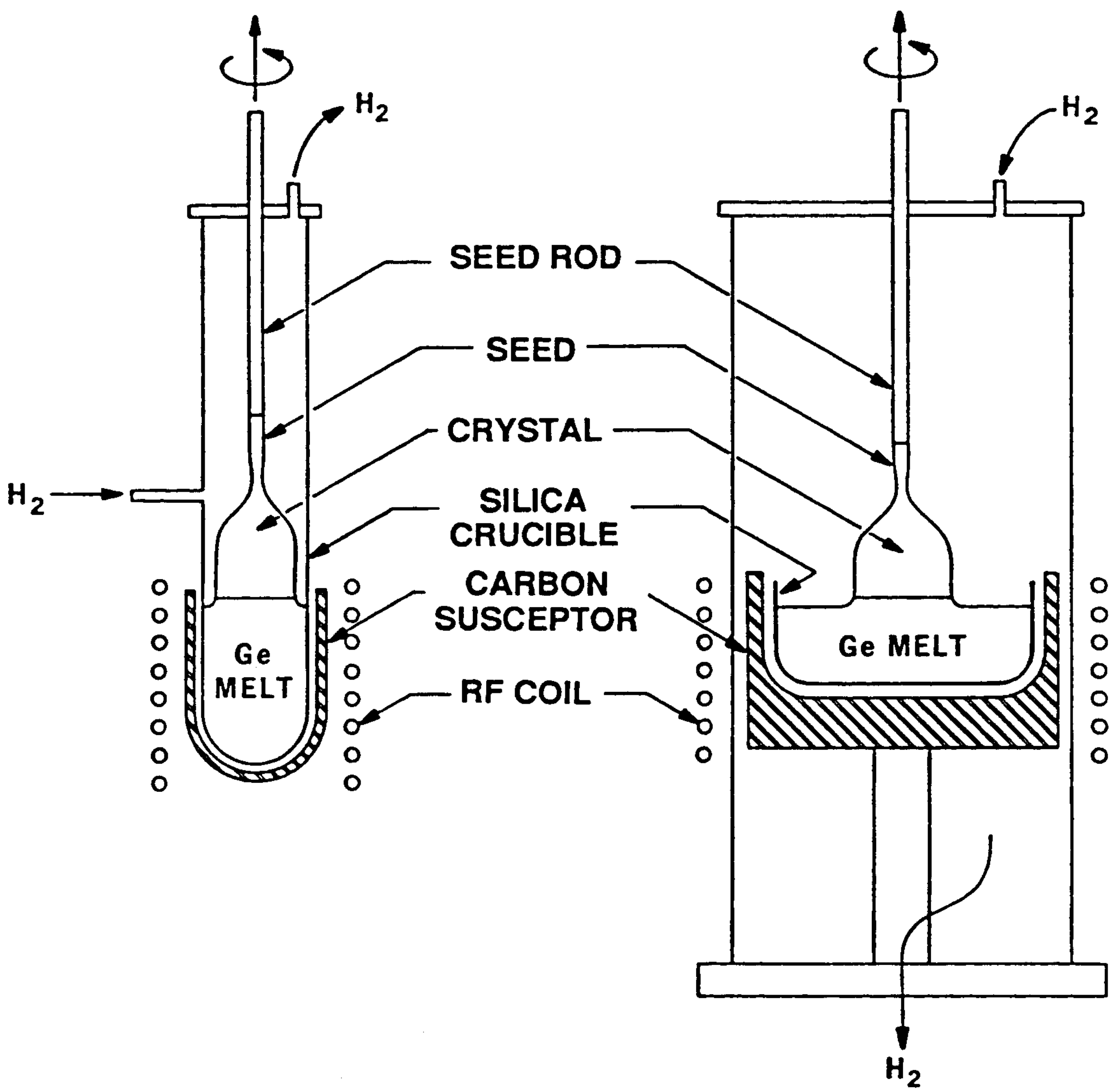


(from E. Haller)

Depletion of large volumes requires low doping concentration.

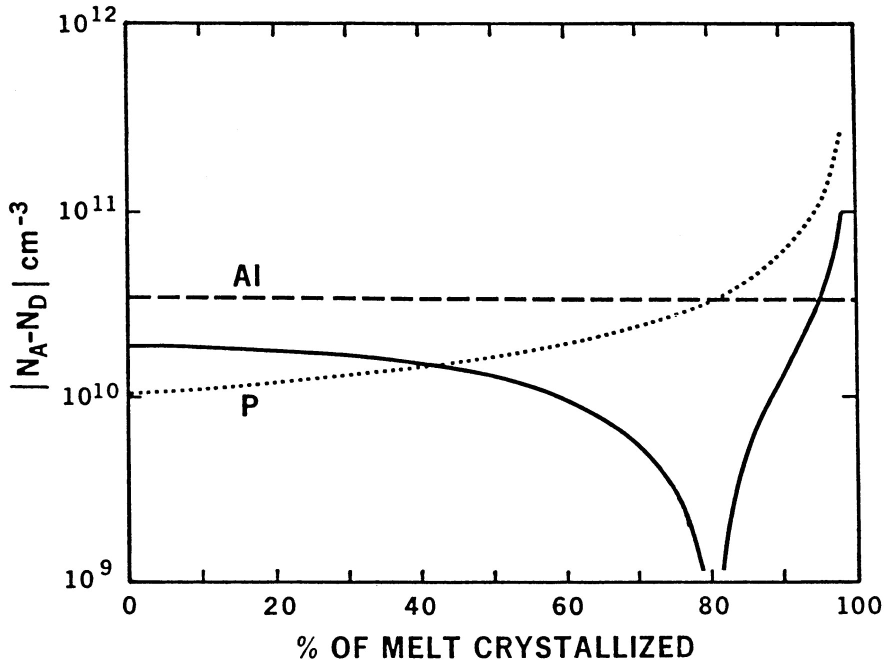
Utilize High-Purity Germanium (hpGe)

Growth techniques developed at LBNL by E. Haller, W. Hansen.



(E.E. Haller)

Typical impurity profile along length of crystal



(E.E. Haller)

Attaining high purity relies on segregation of impurities during the growth process. Typical impurities in Ge have unique segregation properties.

- Aluminum is an acceptor in Ge. It does not segregate in silica grown Ge, so the concentration is constant.
- Phosphorus is a donor. It segregates, so the concentration changes along the length of the crystal.

The net doping concentration is the difference $N_A - N_D$.

- Where the acceptor concentration is larger, the crystal is p-type.
- Where the donor concentration dominates, the crystal is n-type.

The solid line shows the net impurity concentration. In this crystal the P concentration equals the Al concentration at 80% of the melt frozen. The net impurity concentration is very small in this region, so relatively small voltages can form large depletion widths.