Mercuric Iodide And Gas Detectors

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Workshop on the Experimental Equipment for RIA

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Outline

- Overview of Mercuric Iodide and gas detectors offered by Constellation Technology Corporation (CTC)
- Material properties of solid state detectors
- Mercuric Iodide (HgI_2) gamma-ray detectors
- Future prospects and challenges

Introduction To Constellation Technology Corp. (CTC)

- Established in 1992
- Assumed control of DOE's Pinellas Plant Analytical, Environmental and Processing Laboratories
- Employee-Owned/Small business
- 72 employees
- Annual sales $10.2M

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Types of Detectors produced at CTC

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- Radiological detection
  - Solid state Mercuric Iodide (HgI_2) detectors
    - x-ray & γ-ray
    - photodetectors
    - single charge carrier
  - Gas detectors
    - ionization
    - electroluminescence
    - scintillation

$$\tau_{pe} \cong \text{constant} \times \frac{Z^n}{E_\gamma^{-7/2}} \quad , n = 4 - 5$$

Material Properties

Summary of some material properties:

	Z	E_G (eV)	E_{pair} (eV/ehp)	ρ_i at 300 K ($\Omega \cdot$cm)
Ge	32	0.66	2.9	50
Si	14	1.12	3.6	$\sim 10^4$
CdTe	48/52	1.4	4.4	10^9
CdZnTe	48/30/52	1.6	4.7	10^{11}
HgI_2	**80/53**	**2.1**	**4.2**	**10^{13}**
GaAs	31/33	1.4	4.3	10^8
Diamond	6	5	13	$>10^{13}$
TlBr	81/35	2.7	5.9	10^{11}
InP	49/15	1.4	4.2	10^7

Also: SiC, PbI_2, GaSe

TE Schlesinger & RB James, Semiconductors for Room Temperature Nuclear Detector Applications, pg. 470 (1995)

Material Properties

Material properties relevant to tracking detectors:

	ehp created per keV	Density (g/cm^3)	$\mu\tau_{e/h}$ (cm^2/V)
Ge	350	5.33	>1 / >1
Si	280	2.33	>1 / ~1
CdTe	225	6.2	10^{-3} / 10^{-4}
CdZnTe	200	~6.0	10^{-3} / 10^{-6}
HgI_2	**240**	**6.4**	**10^{-4} / 10^{-6}**
GaAs	230	5.32	10^{-5} / 10^{-6}
Diamond	80	3.51	10^{-5} / 10^{-5}
TlBr	170	7.56	10^{-5} / 10^{-6}
InP	240	4.78	10^{-5} / 10^{-5}

TE Schlesinger & RB James, Semiconductors for Room Temperature Nuclear Detector Applications, pg. 470 (1995)

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μ·τ Measurements

$$\mu = \frac{d^2}{V_b t_r} \quad ; d = \text{detector thickness}; V_b = \text{detector bias}; t_r = \text{transit time}$$

$$\tau = -\frac{1}{m} \quad ; m = \text{slope of linear regression line fit to } \ln\left(1 - \frac{q}{q_o}\right) \text{ vs. time}$$

^{137}Cs (662 keV)

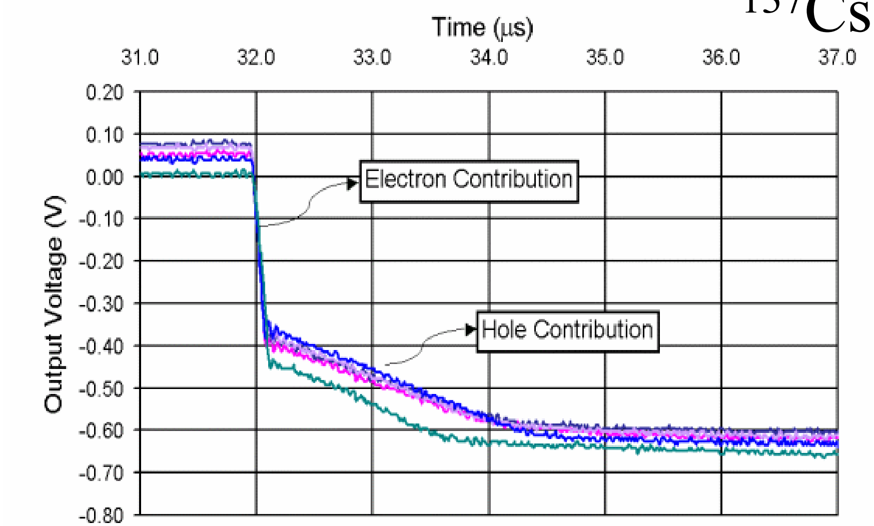


Figure 1. Pulses with Significant Hole Contribution in a Detector

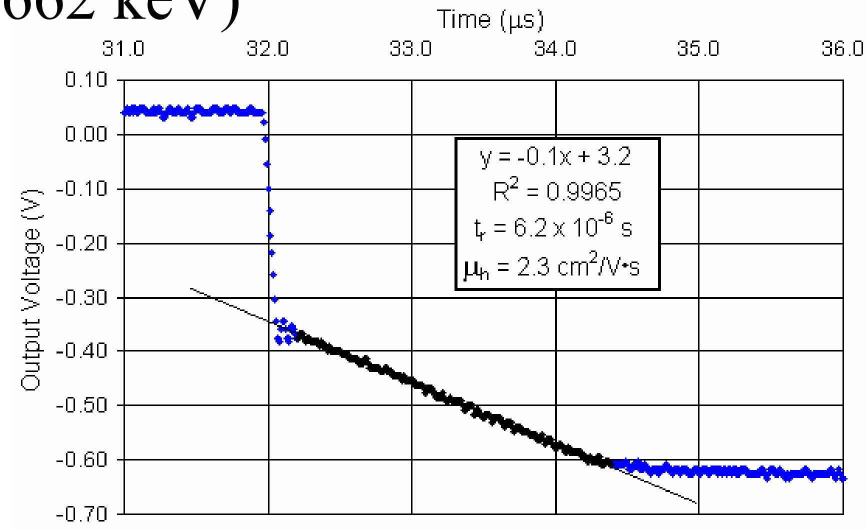
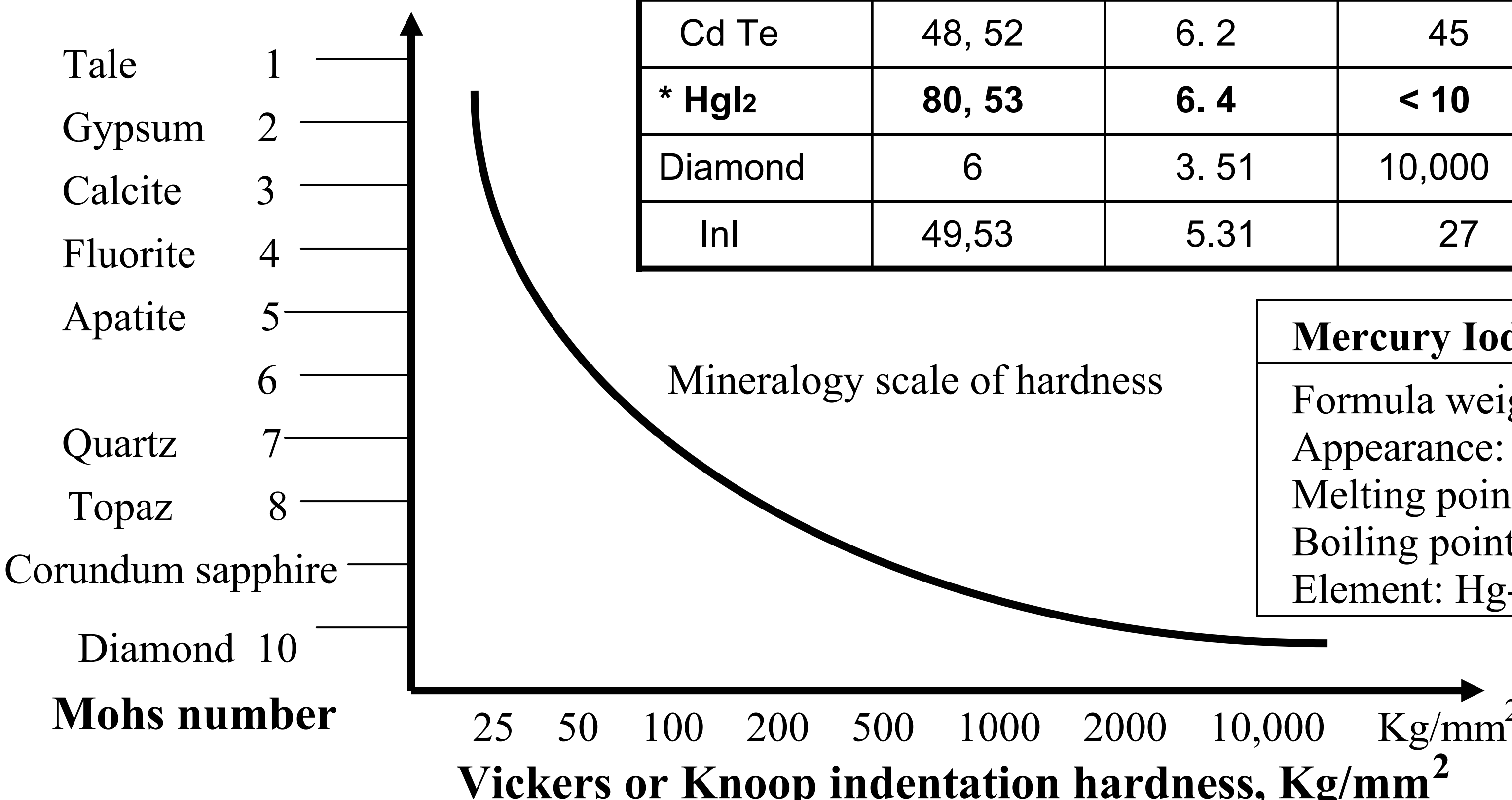


Figure 2. Hole Mobility Analysis for an Individual Pulse

Mechanical Properties

Hardness is a very important characteristic for cutting. Hardness of materials can be estimated according the scales of Brinell or Rockwell. Hardness of Mercury Iodide is shown by the Knoop scale.

Material	Atomic Number	Density, g/cm2	Knoop Hardness
Si	14	2. 33	1150
Cd Te	48, 52	6. 2	45
*** HgI2**	**80, 53**	**6. 4**	**< 10**
Diamond	6	3. 51	10,000
InI	49,53	5.31	27



Mercury Iodide, HgI_2

Formula weight: 454.399
Appearance: crystalline solid
Melting point: 257 C
Boiling point: 351 C
Element: Hg-44.14%; I-55.86%

Radiation Hardness of CdZnT and HgI_2

CdZnTe

200 MeV protons: >25% gain shift in strip detectors after $5x10^9$ p/cm^2

Moderated neutrons: significant degradation after $7x10^{10}$ n/cm^2

Thermal neutron activation of ^{113}Cd produces gamma lines from 10^{10} n/cm^2

A. Cavallini et al, NIM A458 (2001) 392-399

HgI_2

10 MeV Protons: no ΔE loss up to 10^{12} p/cm^2

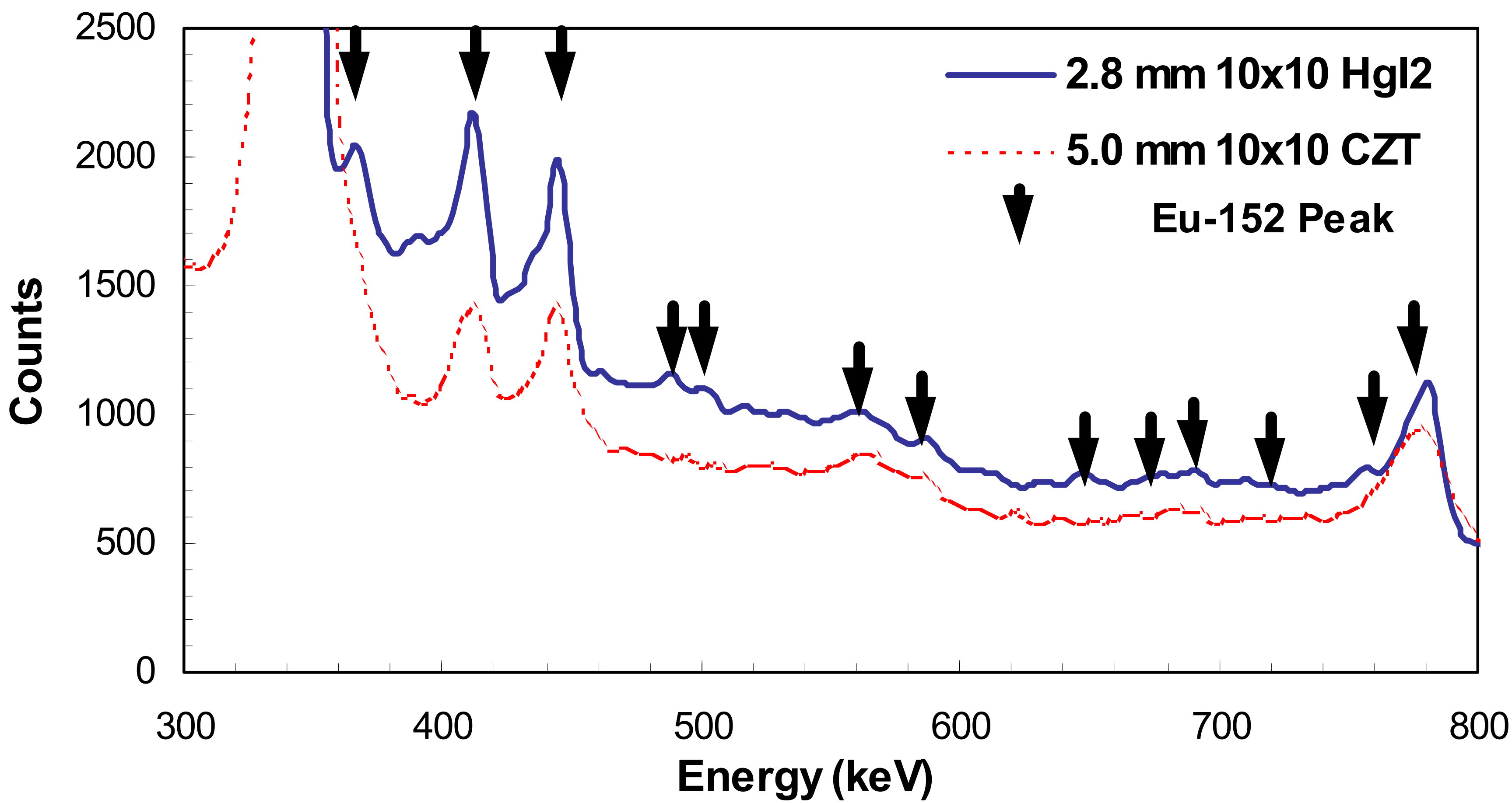
8 MeV neutrons: no ΔE loss up to 10^{15} n/cm^2

$\Rightarrow$ More studies of HgI_2 are needed

FD Becchetti et al, IEEE Trans Nucl Sci 23 (1976) 468

Mercuric Iodide and Coplaner Grid CZT

Eu-152 Point Source On-Axis, 10 cm



Mercuric Iodide and Coplaner Grid CZT

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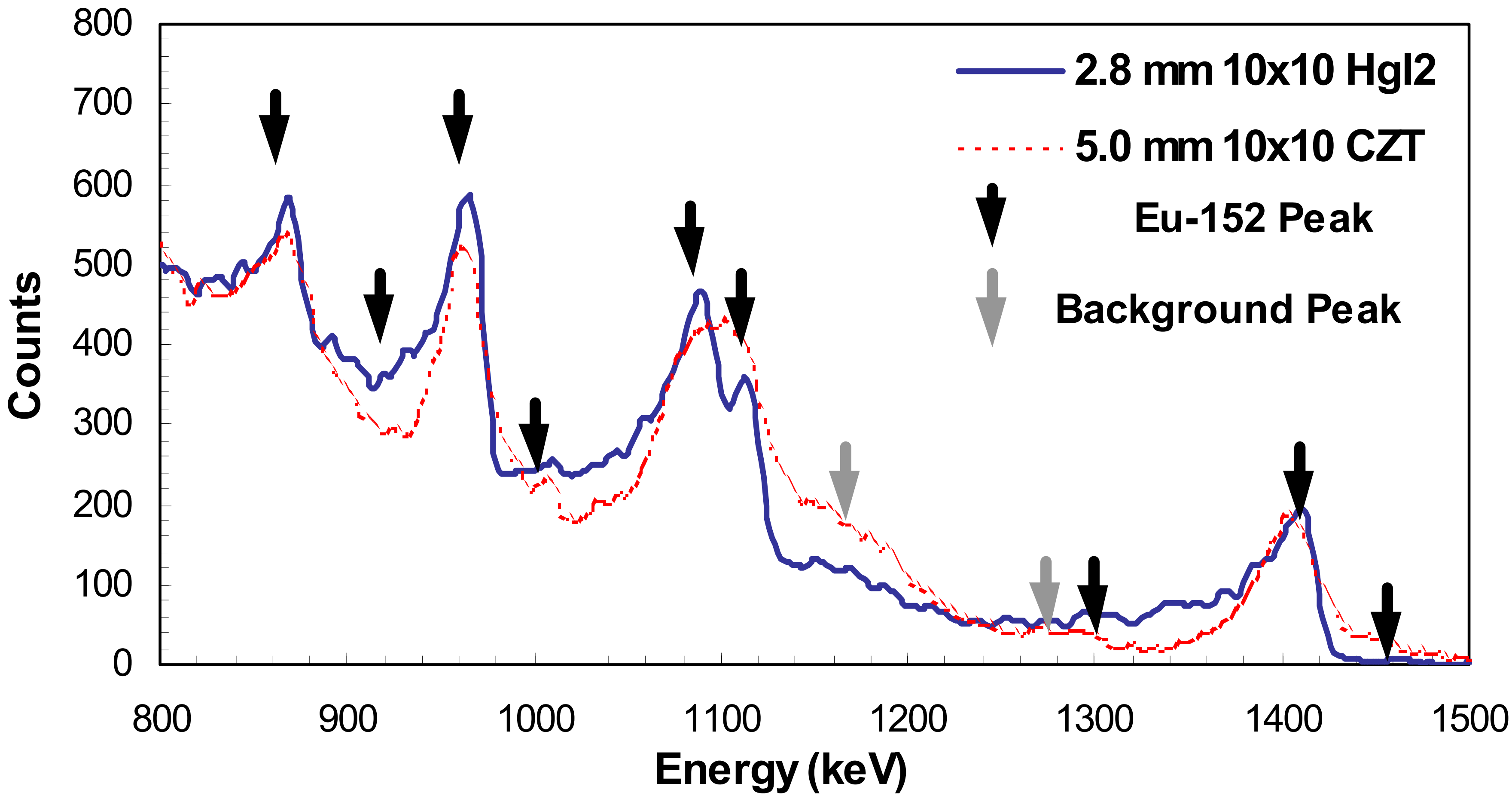
Eu-152 Point Source On-Axis, 10 cm



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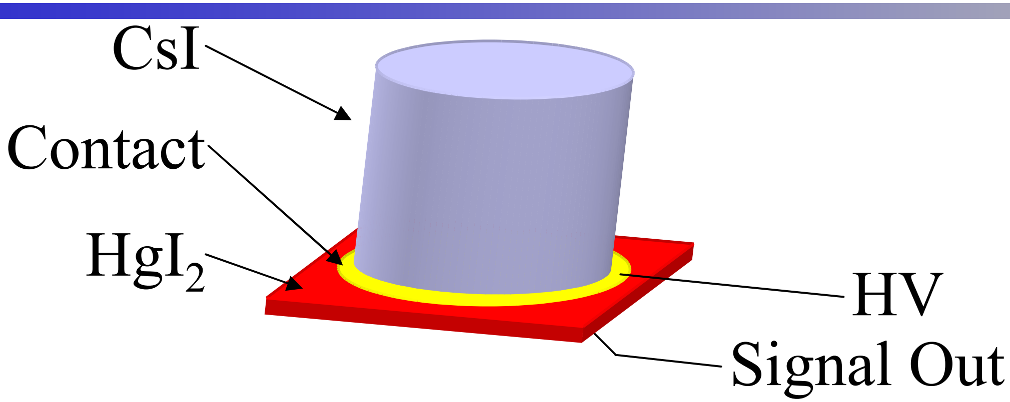
γ-ray Detectors

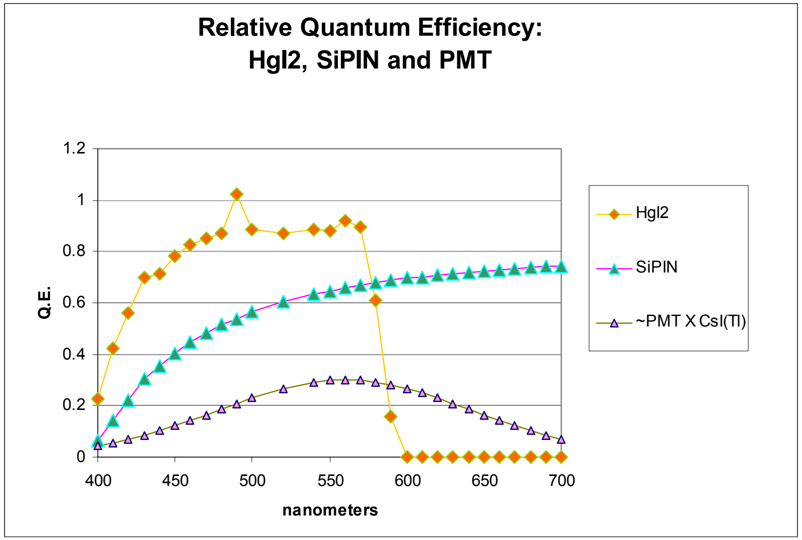
Detector Area	Thickness (mm)	FWHM @ 662 keV
10 mm x 10 mm	1 - 2.5	< 3 %
25 mm x 25 mm	1 - 2.0	< 3 %

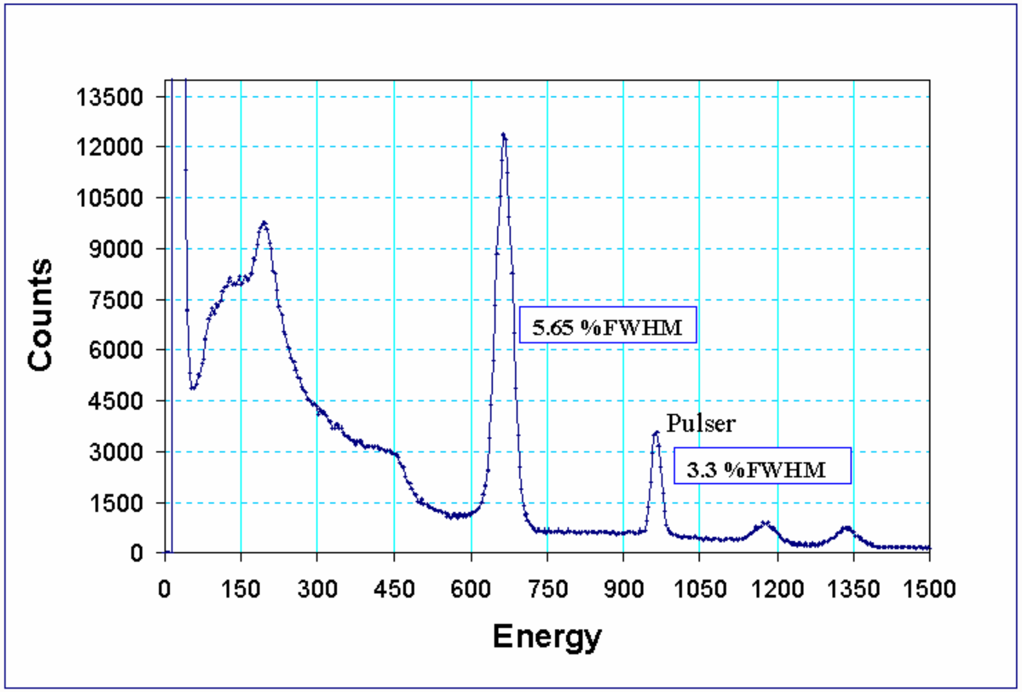
Photo Detectors



Signal from HgI2 is 5 times higher than that from the CsI light pulse

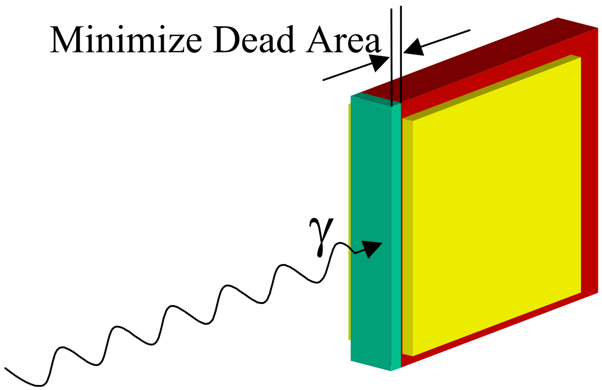
HgI_2 has excellent quantum efficiency from ~ 400 - 600 nm



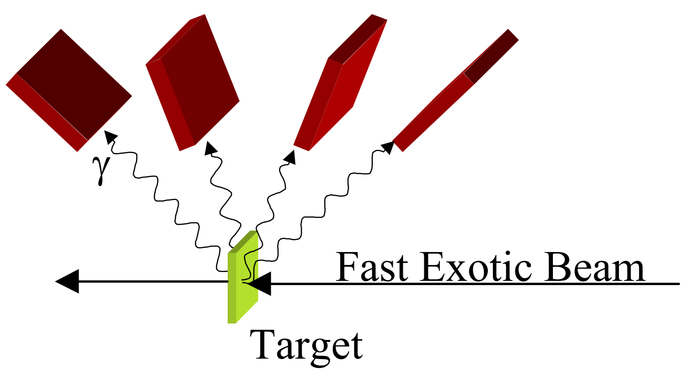


Future HgI_2 Detectors

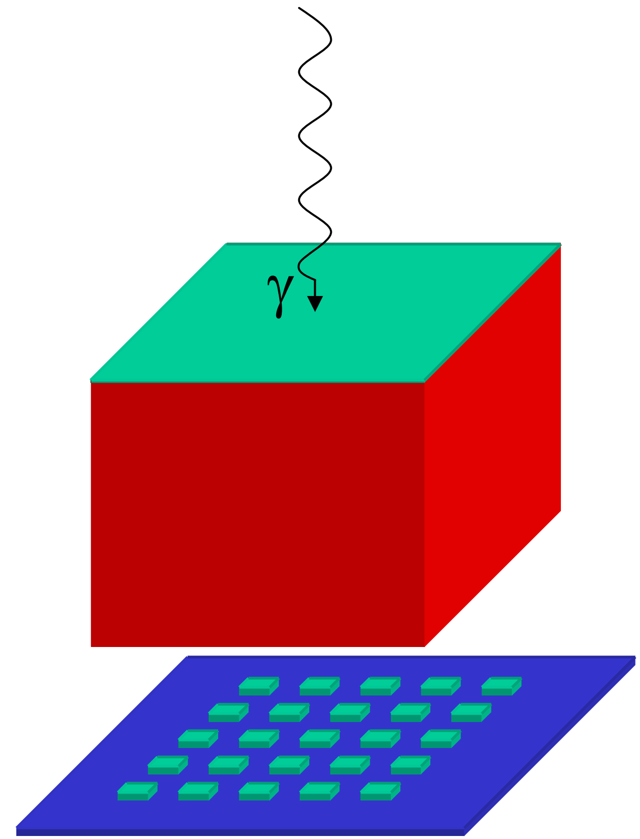
Detectors designed for edge detection



10 mm x 10 mm x 2 mm



Single charge carrier detectors



Z He, U. of Michigan, 2002

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Outlook

- CTC is developing even better material for single crystals
- CTC is developing a production level single charge carrier device
- Need more research in the areas of radiation hardness and high dose characterization.
- Need a better understanding of the charge transport and defect mechanisms in HgI_2

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Detector Development Group

RIA

- **Anatoli Arodzero**
- Juanita Baker
- Aleksey Bolotnikov
- **Alexander Bolozdynya**
- **Ray DeVito**
- Philip Diebold
- Leo Godbee
- Jhames Illanez
- Scott McPherson
- Christel Munoz
- Alan Proctor
- John Richards
- Mark Rutter
- John Sandoval
- Brian Sonnenberg
- Laurel Szubart
- Chris Traynor
- Lodewijk van den Berg